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ON THE FLUTE

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THEOBALD BÖHM, AGED 60.

AN ESSAY

ON THE

CONSTRUCTION OF FLUTES,

GIVING A HISTORY AND DESCRIPTION OF

The most Recent Improvements,

WITH

AN EXPLANATION OF THE PRINCIPLES OF ACOUSTICS
APPLICABLE TO THE MANUFACTURE OF
WIND INSTRUMENTS.

ORIGINALLY WRITTEN IN 1847 BY

THEOBALD BÖHM,

Of Munich.

AND NOW FIRST PUBLISHED.

EDITED, WITH THE ADDITION OF CORRESPONDENCE AND OTHER
DOCUMENTS, BY

W. S. BROADWOOD.

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PREFACE.

The pamphlet—now published for the first time, and giving an account of the various alterations and improvements made by Böhm in the flute—was written by him, in English, for Mr. Rudall, in 1847; probably with a view to explain the principles on which the Böhm Flute was constructed, and, also, to set forth the advantages of the particular (cylindro-conical) form of it, for which Messrs. Rudall & Rose were then taking out a patent.

Mr. Rudall, however, did not care to publish the treatise. It was laid aside, and forgotten until quite lately; when, soon after Böhm's death, certain public attacks upon his character, coupled with a denial of the originality of his invention, drew from me a reply. This reminded Mr. Carte, the present representative of the firm of Rudall & Rose, that he possessed Böhm's own account of all the circumstances in dispute, and he was good enough to send it to me. The pamphlet, which is in Böhm's own hand-writing, as I can vouch, has an interest of its own, wholly distinct from the facts relating to Böhm's connection with Gordon. I imagine it will be read with no little pleasure by most flute players, whether professional or amateur, giving us, as it does, a clear and succinct summary of those principles of acoustics which are applicable to the construction of all wind instruments.

I should suppose that the Böhm *versus* Gordon much-debated controversy would now, by impartial persons, be considered as settled—all the more that our much-injured "countryman" turns

out to have been a Swiss. Yet determined partisans are not easily daunted, and we know that, though we

> "Convince a man against his will,
> He's of the same opinion still."

I had not seen Böhm's pamphlet when I replied to the accusation, that by stealing another man's invention, shown him in confidence, he had driven that man to despair, insanity, and suicide, while acquiring for himself unmerited distinction. I am glad to see that Böhm, both in this pamphlet and in his letters, has anticipated my defence almost literally. He says that the so-called Böhm fingering *was* invented by himself; and Gordon's acknowledgment, printed with his table of fingering, goes far to prove the assertion. And Böhm goes on to say that he never attached very much value to the fingering alone, but that his really important achievement was the successful substitution of acoustic theory for mere empirical experiment in the construction of several varieties of wind instruments. "For *this*," he says, "is the chief foundation of the higher or lower degree of perfection in all instruments, their mechanism being but of secondary importance. *It is also much easier to construct keys than to improve notes.*" I propose to reprint in an appendix my own article, originally, most courteously, published in the *London Figaro* as well as in the *Musical World;* also the much more important paper written about the same time by Dr. Schafhaeutl, of Munich. These, with Böhm's own account, give at all events his side of the question as to the authenticity of the invention, which, however, in no degree affects the inherent interest of his English pamphlet.

In going through this latter, I have been careful to avoid all unnecessary interference with the original text. Böhm wrote and spoke English very fluently; and in ordinary conversation expressed himself very correctly. All who have taken the trouble to acquire a more than merely superficial acquaintance with foreign languages will know that it is one thing to converse and write on general and indifferent subjects; another, and a very different thing, to attain such a command of accurate and technical terms as may

be necessary for even a popular explanation of scientific subjects. Your German, also, revels in parentheses; he loves to string them together like old bills on a file, until, having made up a sufficient bundle, he clinches the whole with the long suspended verb, and so finally reveals his meaning. We Britons cannot wait so long; we love to get direct to our object. To some of us possibly, the delay is not only irritating, but even confusing: and for this reason I have ventured to unravel certain phrases of Böhm's, which were much more akin to German than to English, and in the nature of a compromise between the two languages, my effort always being to express what I took to be his meaning, in the fewest and most direct words. After all, these alterations do not amount to very much; and may almost be classed with the correction of "clerical errors."

I will include in the Appendix, extracts from Böhm's letters, of which I have kept a considerable number; because there is much in them of general interest; and a good deal which goes to show that Böhm was not the "ignorant impostor" I once heard him called by a gentleman whose claim to celebrity rested on the invention of a key, which Böhm (a plagiarist by anticipation) had already used for his oboe fingering some years before. The answers to various questions as to pitch, bore, position of holes, &c., which I have quoted, show beyond doubt, that Böhm understood his subject thoroughly; they also afford practical, and often very useful hints for the management of flutes, and the application to them of theory, as laid down in the pamphlet.

Böhm's flute was not only an improvement on the "old flute," but differed from it so materially in character and colouring of tone, that it has on this account been excluded from some of the Continental orchestras. In France it is generally used, but certain German conductors appear to have considered that the Böhm flute does not take its proper place in that gradation of "wood" instruments, which, commencing with the bassoon, culminates in the piccolo. In power and breadth of tone, sometimes also in quality, it approaches too near the clarinet to give the balance of tone, which writers—like, for instance, Mozart (whose minute

appreciation of the characteristics of each instrument is very striking)—would seem to have aimed at. Of course very much depends on the individual artist, who may use, or may abuse, the increased power of his instrument. The silver Böhm flute, when used (as is now rarely the case) in the orchestra, stands out perhaps too distinctly from the other instruments. The tone will not blend. I have heard it from the further extremity of an exhibition building, apparently playing isolated phrases, without accompaniment; as I approached, the double basses became audible, then came the violins; but the silver flute was heard before them all. Its blowing, however, requires very peculiar management. Böhm constantly insists on this in his letters; and certainly his own tone was wholly free from all shrillness when he played on a metal flute. I think the same might formerly be said of Mr. Svendsen's tone when he used a silver flute. The contrary is more generally the case; but Mr. Svendsen is an admirable artist, and his tone is exceptionally good on the wooden flute also. In his pamphlet, Böhm alludes to the effect produced by players on the old flute; and in one of his letters he says that, but for Nicholson, he should never have attempted any radical change of system. He despaired of rivalling Nicholson's great power with any but an improved instrument, and so set to work to devise one.

Those who, like myself, remember Ciardi, will admit his performance to have been a rare instance of what could be done on the old flute. He played on an old wooden instrument by Koch (I think) of Vienna, with a crack down the head joint, which, as I remember, much exercised the mind of Mr. Rose; yet I have heard him sustain a *crescendo* for four consecutive bars of *adagio*—after which I took him (he had only just arrived) to Mr. Rudall, who, not speaking Italian, begged me to explain that he, Ciardi, "was fit to play before a chorus of angels."

Ciardi was encored (his entire piece) in a concert at the Opera House, where Grisi, Mario, and Tamburini were waiting to be heard; and in consequence was engaged to play a solo at the classically exclusive Philharmonic, whose members he shocked

prodigiously by playing a fantasia on airs from *Lucia*. His tone, colouring, and facile execution, always faultless in its elegance, carried all before it; and when the more eclectic subscribers had subsequently swallowed a bit of high-dried Corelli, they felt better. Another performer on the old flute produced an equally remarkable, though different, sensation at the same society's concerts. This was a gentleman from Holland, noted for his power of sustaining *chords* on the flute. So astonished was Mr. Clinton (then a director, and himself unable to play more than one note at a time on the flute), that he introduced the Dutchman, and obtained for him a preliminary hearing. I was present at that Philharmonic rehearsal, and well remember the brilliant and rapid *staccato* articulation with which the special wonder was ushered in. Presently came a pause; then, amid deep silence and breathless expectation, the player emitted three several simultaneous sounds (I doubt whether Böhm has accounted for more than one of them on his diagram), which were greeted by the orchestra and its conductor (Sterndale Bennett) with one vast, irrepressible shout of laughter. When this subsided the Dutchman had fled, and Mr. Clinton might be observed looking doubtfully about him, wondering, perchance, whether he had been beguiled by that legendary being, since dramatized by Wagner, and impersonated, though not as a flautist, by Mr. Santley.

We need not, however, go beyond our own present day for an admirable example of what may be done in the orchestra with the old flute. Those who are in the habit of attending the Crystal Palace Concerts will doubtless agree with me, that in point of execution, tone, and intonation, Mr. Alfred Wells leaves little, if anything, to be desired. This he modestly attributes to his instrument; whereas I make bold to assert that the secret lies with the player, who charms us in spite of the possible defects (for I have not noticed them) of his flute.

These are perhaps exceptional cases. We know that Picco, the blind shepherd-boy, astonished the town a few years since, by playing every sort of brilliant variation on a whistle having four holes only. And I remember a Styrian peasant learning by ear (in my presence) from a Viennese musican a difficult air from the

Zauberflöte, involving all sorts of scales and chromatic intervals; which he produced accurately, and with apparent ease and certainty, on a threepenny keyless fife. This the player afterwards bestowed upon me, giving me great hopes of future celebrity, because I made one note sound. I have the fife still.

Nevertheless, I for one consider that flute players—not to say musicians—owe a debt of gratitude to Böhm. He died November 25th, 1881, aged 86; and I have endeavoured to show my respect, by rescuing from oblivion this work of my old and honoured friend.

W. S. BROADWOOD.

April, 1882.

A HISTORY

OF THE

INVENTION OF THE BÖHM FLUTE.

My newly constructed flute of the year 1832 is at present very generally adopted. Notwithstanding the prejudices which retarded its progress, and the necessity of practising an entirely new system of fingering, it is now played by numerous and eminent artists of all countries. My system has been already applied to many other wind instruments, and the authenticity of its invention has even given rise to public discussions.

The superiority of my invention being thus appreciated, it may not appear improper to publish, in answer to many and repeated calls on me, an account of the origin of my flute, and of my reasons for its construction.

Well practised from my early youth in my father's business, not only as a goldsmith and jeweller, but also in mechanical works and constructions, I was able easily to make a flute for my own use; and I began to play upon it in 1810. With my progress in music, the desire for better instruments grew in proportion. I constantly attempted improvements, and more than thirty years ago I applied to my flutes new sorts of springs, linings, cork on the joints, a movable golden embouchure, and many other things now generally used.

In the year 1812 I was already first flute at the second Royal Theatre in Munich; and after having obtained my appointment in the king's chapel, in 1819, I left my business as jeweller, and devoted myself entirely to music.

Subsequently, having for several years had flutes made according to my designs by other instrument makers, but without satisfactory results, I resolved to establish a flute manufactory of my own.

By October, 1828, I was at work in my well-fitted shop, and began to construct various machines for making with more facility and accuracy a better sort of key mechanism than was in use previously; and before the year was over, I had finished a flute which met with general approbation for quality of tone and intonation, as well as for elegance and solidity.

On a flute thus improved, but constructed on the old system, I played in 1831, first at Paris, and afterwards in London; where I was struck with the powerful tone which Charles Nicholson, then playing with all his energy, was able to produce. This was owing to the uncommon largeness of the holes of his flute, and the consequent freer development of the notes. But it required Nicholson's extraordinary talents and excellent embouchure to conceal the defects of his flute in regard to intonation and equality of tone—defects which were owing to the incorrect position of the holes.

At the same time I became acquainted with Mr. Gordon, a dilletante on the flute, who had formerly in Paris, and later in London, tried to make improvements on his instrument. The E hole of his flute was bored lower down than usual, and was covered with a key; and to avoid the F lever he made use of a ring-key. He had also on his flute a number of keys and levers, some of which were ingeniously devised; but they were much too complicated, and of no use, as the instrument wanted throughout a correct acoustical basis.

Strengthened by all this in the conviction that no essential improvement could be made without a total change in the system of fingering, I resolved to adopt neither the large-holed ordinary flute, nor other mere mechanical changes, but rather to spend time and trouble upon the construction and practice of a *totally new flute*, in which equality of tone and pure intonation should be united with the means for executing every possible combination of notes by a *new kind of key-mechanism*.

On my return to Munich, in 1831, I began immediately the execution of my project; and, after having carefully re-examined different bores, and several systems of fingering which I had sketched out before, I decided upon that with ring-keys as, on the whole, the best. (Fig. 3.)

The success answered my expectations. In a few months I had acquired the facility of playing at concerts and in the orchestra; and in Munich, as well as in London, where I again played in 1833 and 1836, the full and even tone, and the pure intonation of my flute, were immediately observed and appreciated.

Many flute players and instrument makers examined it, but most of them were discouraged by the new system of fingering. Flautists of old standing decided against it, because they could not resolve upon studying an entirely new instrument; and, possibly, they sometimes saw with displeasure that young artists, by adopting it, acquired an accession of means for producing greater effects in their performance. Most of the instrument makers were against it, because they found it inconvenient or unprofitable to imitate a sort of key-mechanism quite new to them.

In the conviction that what is good works its own way, I published nothing but a scale of fingering for my flute; and as I was from the year 1833, during eight years, more occupied with steel and iron works than with music, there were but few teachers and pupils for my instrument, and its progress was for a long time very insignificant. In the year 1837 I had occasion to exhibit my flute, with a short explanation of its advantages, at the Academy of Sciences at Paris, and the report given by the committee of examination (Messrs. De Prony, Dulong, Savart, Paer, and Auber) was very favourable. Soon after, my flute was adopted exclusively by many of the most distinguished artists in France, England, Germany, and Italy—such as Messrs. Dorus, Camus, Clinton, Carte, M. Fürstenau, Heindl, Stettmaier, Briccialdi, &c., &c.—and thus prejudice gave way to the full acknowledgment of its value.

This caused divers interests to arise. In London there are at present several flutes of different construction, and much is disputed on their comparative excellence; in Paris the simple open G♯ key of my flute was exchanged for a very complicated shut G♯ key, under the pretext of improvement; and some one found it also convenient to ascribe my invention to the above-named Mr. Gordon, who could no more protest against the compliment, as he had died before.

I myself had never placed a high value on this my invention. I was satisfied with the approbation of some impartial and competent judges, and with having an instrument free from many defects of the old flute.

But though I at that time took no patents for my flute*, and left it free for use and imitation, I am not inclined to be deprived of the authenticity of my invention. I find myself obliged, therefore, to show my relations with Mr. Gordon more clearly.

At the beginning of 1832 my new flute was completed; and not only was it known in public by my playing upon it, but I had also sold already several of these instruments, when I received the following letter from Mr. Gordon, the original of which is in my hands:—

"Lausanne, 15 Feb., 1833.

"Mon cher Monsieur!

"Je suis depuis quinze jours de retour chez moi à Lausanne, après un séjour assez long à Paris, où je suis venu de Londres peu après vous avoir vu, lorsque vous en êtes parti pour Munich.

"Je n'ai pas perdu mon temps, et j'ai travaillé avec persévérance à une flûte nouvelle, que j'ai faite moi-même aussi bien que j'ai pu, et que je viens de terminer.

"Je ne vous ai point oublié, et j'ai toujours attendu que vous m'enverriez une flûte perfectionée que vous proposiez de chercher à faire à votre retour en Allemagne. Selon votre offerte à Londres, je veux vous envoyer ma flûte, en vous priant de m'en faire une

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* The patent taken out in 1847 was for the combination of a cylindro-conical tube with Böhm's fingering.—W. S. B.

belle sur ce modèle ; vu que je possède entièrement le doigté pour la jouer. Je vous enverrai en même temps la tablature du doigté.

"Je n'ai pas voulu vous envoyer ma flûte avant d'avoir reçu de vos nouvelles. Veuillez donc m'écrire à l'adresse ci-après : À Monsieur Gordon à Lausanne en Suisse, et me dire la manière que vous croyez la plus sûre de vous la faire parvenir sans accident ; et si vous pourriez m'en faire une semblable, vous en occuper le plutôt possible. Dans l'espérance que ma lettre vous trouvera à Munich, je vous l'envoye à l'adresse que vous m'aviez donné.

"Acceptez l'assurance de toute ma considération.

"Votre dévoué serviteur,

"Gordon."

Some months after my reply to this letter Mr. Gordon came himself to Munich, and soon became convinced of the effects of his flute in comparison with mine. He rejected his system, and began trying another, for the execution of which I allowed him to make use of my workshop and my workmen. After a twelvemonth, when he had two flutes completely destroyed by continual alterations, he left Munich with the flute represented in Fig. 1. He named his flute quite erroneously "Flute diatonique," as only the old flute with six holes is diatonic, but all those since furnished with keys, are chromatic. He published also in 1834 an engraved scale for his flute, which he gave to me ; and in the letter-press accompanying this scale, he observes among other things :—

"La suppression des deux clefs de Fa naturel, et leur remplacement par une clef de Fa dièze, est une idée dont l'application offre des grands avantages. L'idée de cette clef de Fa dièze *communiquée par Mr. Th. Boehm de Munich, a été, avec son agrément, adoptée pour la présente flûte, dont elle complète les moyens d'exécution.*"

But so far as I know, Gordon's flute was neither imitated nor played by any one else ; and afterwards, when I met him again in London, he wished to have one of my flutes, as he was not satisfied with his own. I have the proofs of all these facts in my hands. How then could my flute be an imitation of his, which was made under my own eyes more than a year after mine had been completed ?

Mr. Gordon made use of essential parts of my instrument when he constructed his; but he, a gentleman in every respect, always legally acknowledged it.

But the surest proof of the authenticity of my invention may be a statement of my motives for constructing a new flute, and the explanation of the acoustical and mechanical principles I made use of; for he alone is capable of producing a rational work who is able to account for every detail, from its conception to its completion.

It may not be superfluous to answer here a question formerly often put to me, and appearing perhaps to many, even now, not unfounded, viz:—"Is it worth while to throw away the laborious practice of years, and to begin again the study of an entirely new system of fingering, when long before, and even now, the performances of many artists have been thought excellent?"

It certainly admits of no doubt, that genius and great talents have at all times found due appreciation; but no one will dispute that Mozart, though he was able to charm his auditory on a spinet, would have produced a still greater effect on a modern pianoforte.

All criticism depends on comparison. A spinet, or a flute with one key, would, without the knowledge of better instruments, pass for being good, particularly if the artists were cautious not to expose too much the defects of their instruments.

But if any one should perform at present, on a flute with one key, compositions in E flat, F sharp, &c., &c., the audience would doubtless be very dissatisfied. The instrument is to the artist what the voice is to the singer, the organ for the transmission of his sentiments, and for the manifestation of his taste and skill. The more this organ is perfect, the more the genius of the performer, as well as of the composer, will be supported.

To show the improvements which I have conferred upon the flute, I think it unnecessary to give a history of that instrument, as it will be sufficient, for the sake of comparison, to point out some defects of the common flute in its former state.

Though the correctness of the octaves, and the easy emission of tone, unquestionably gained much by the adoption of the cone from the beginning of the middle joint down to the lower end of the

flute, the acoustical proportions became at the same time much more complicated than in the original old cylindrical flute; therefore all known theories are of little use, particularly for modern flutes, in which the sections of the columns of air occur, for the lower notes, at such distances one from the other, that the holes, if placed according to rule, could not be covered with the fingers.

The instrument makers of former times, ignorant of key-mechanism, could not do otherwise than place the holes—without regard to acoustical principles—at such distances from each other that the fingers could still reach them. Afterwards a better chromatic scale was obtained by the adoption of keys; but as the position of the holes of the old diatonic D major scale remained the same, their incorrect position (by which the nodes of vibration were often disturbed) and their insufficient size not only diminished the easy emission and pure intonation of some high notes, but also lessened the clearness and power of the tone throughout the instrument.

These defects could not be removed without an alteration in the old system of fingering; but the greater facility of execution gained by this alteration has another merit, because it is an immense gain to the composer when instruments can be used to the full extent of their compass, without regard to key or to difficulty.

In our days, on nearly all wind instruments, the artist can execute passages which were impracticable in former times. From the flute player in particular is required that he shall have an absolute command of tone and intonation throughout the whole compass of his instrument, both for *pianissimo* and *fortissimo*; and he ought to play all sorts of passages with every possible kind of articulation. There is no doubt that many artists have carried perfection to its last limits on the old flute, but there are also unavoidable difficulties, originating in the construction of these flutes, which can neither be conquered by talent nor by the most persevering practice.

Thus passages are often met with in music for the orchestra, much more difficult than in any concertos composed by flute players, who, acquainted with the defects of their instruments, are generally prudent enough not to prepare for themselves such stumbling-blocks.

Among such defects are to be reckoned all those notes which sound with difficulty or uncertainty; those which cannot be sustained in a *crescendo* or *diminuendo* without the risk of the tone "breaking;" and those that require great management of lip to preserve a pure intonation.

The question which now arises—"To what extent, and by what means, these defects were obviated in my flute of 1832?"—will, as I think, be answered by an exact description of the acoustical proportions and mechanism of that instrument.

Though I was, even then, pretty well acquainted with the general laws of acoustics, I could find scarcely any guide for their special application to the construction of flutes; and I was therefore obliged to have recourse to many merely empirical experiments before I determined upon the following proportions of the tube or column of air as most suitable for my purpose.

	In English feet.	In French metres.
I.—Head Joint.		
Length of the cylinder from the cork to the middle joint	0.4593 ..	0.1400
Width of it	0.0604 ..	0.0184
II.—Middle Joint.		
Length of the cone	1.1417 ..	0.3480
Width at the upper end	0.0604 ..	0.0184
Width at the lower end	0.0393 ..	0.0120
III.—Foot Joint.		
Length of its conical part	0.2624 ..	0.0800
Width at the upper end	0.0420 ..	0.0128
Width at the lower end of this conical part	0.0361 ..	0.0110
Length of the lower cylindrical part	0.1312 ..	0.0400
Width of it	0.0361 ..	0.0110
IV.—Whole length of the column of air	1.9947 ..	0.6080

These proportions being once established, I prepared several tubes, all alike in thickness of wood, 0.0146 ft., and in length, 1.9947 ft.,

for producing the fundamental note C. The embouchures I made in form of a parallelogram with rounded corners, and placed them at a distance of 0.0557 ft., measured from the centre of the embouchure to the cork stopper.

After that, I began to cut off from the lower end of one of these tubes, till I obtained C sharp. I then marked the point of section on a second tube, and repeated this operation till I had got all the notes of the first octave. Then I bored in the second tube holes at the points of section which I had marked before, and these holes I made of the largest size at which they could be stopped with the fingers.

All the notes produced in this way were too flat, on account of the holes being smaller than the tube in diameter, therefore I corrected the tuning on a third tube by moving the holes towards the embouchure. Though I obtained in this way the first and second octaves in correct tune, with equal-sized holes, the third octave was still defective; because, to produce the high notes, it is necessary to open, together with the hole of the fundamental note, the fifth hole above it, as a vent hole; and as the clearness, free emission, and correct tuning of the high notes depend upon the position of those vent holes, I was obliged to move again six of the upper holes, and to correct the intonation, thus disturbed, by modifying their size.

At last, I obtained a tube with fourteen holes, which was very much superior in acoustical proportions to the common flute tube, as all notes from the fundamental C up to the highest B could be produced upon it, equal, free, certain, powerful, and in good tune.

But the position of the holes being now totally changed, a new system of fingering was wanted, in which all holes could be opened or closed, not only in an ascending or descending series, but also in every different combination. This task was not so easy to accomplish, as nine fingers have to stop fourteen holes; the thumb of the right hand being indispensable for holding the flute.

The deficiency had to be made up by key-mechanism, and I chose ring-keys for this purpose. If a finger-hole be surrounded by a groove, into which a ring may be pressed without touching the

sides, and if this ring be fastened to the axle of an open key, the finger necessarily presses down the key while stopping the hole. One finger, performing in this manner two functions by a single movement, does the work of two fingers. A further difficulty, that of not being able to reach some holes with the fingers, I obviated by separating the key-handles from the keys, which I could then bring within reach of the fingers by means of long axles.

With these two contrivances, and some new combinations of keys, I was enabled to establish a system of fingering by which the fingers do not move out of their natural position from the lower D up to the highest B, with the exception of the little finger of the right hand, to which I left the management of the foot-keys, in order to retain as much as possible of the old fingering. There is now no more gliding from one key to another, or to a finger-hole, and this immense difficulty of the old flute being obviated, it is easy to play in every mode (key). (Fig. 3.)

According to my system, the fingering of the chromatic scale is formed in the following manner:—

When all holes are closed, the note produced is ...

By opening the lowest or C sharp key ... ...

By opening the second or D key ... ...

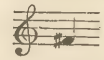
By opening the third or D sharp key ... ...

So far it is all the same as on the common flute.

It is necessary, for obtaining a clear and strong tone, that the holes immediately below the one sounding should remain open, for the air confined in the lower part of the tube tends to flatten the notes, and renders them less free; therefore the D sharp key remains open for the whole of the scale, excepting and thus the little finger of the right hand assists at the same time in holding the flute steadily.

The next three holes are encircled by rings, the two first of which are joined to the axle by the G natural key, and the third is com-

bined with two levers by an axle reaching up as far as to the B natural key. Thus the is produced by opening the fourth or E hole, which is covered by the third finger, and the by opening the fifth or F hole, covered by the second finger.

When the sixth or F sharp hole, covered by the first finger, is opened, the ring-key rises by its own spring; and as thus two holes are opened at once, the note we obtain is two half-notes removed from F natural. To obtain the preceding  the seventh or G natural hole must remain closed by the pressure of the second or third finger upon the ring-key; the second finger, however, being used only in quick passages, on account of the above-mentioned injurious influence of the lower part of the column of air, which only ceases when two holes at least are opened immediately below the sounding hole.

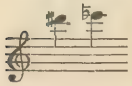
It will be seen that it is easy in this manner to play with three fingers on four holes, and that the ring-key provides a substitute for one finger. We come now to the left hand, by which all holes upwards from G are closed. As my system of fingering is based throughout on the opening or closing of the holes in regular succession, open keys are, on account of their similarity of motion, surely the most natural representatives of fingers where the holes are out of reach.

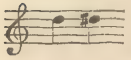
For this reason I have used open keys for all notes of the scale, except D sharp. So, too, the key which closes the G sharp hole remains open, until it is pressed down and closed, as if by the direct action of the little finger of the left hand; and as this open key rises by its own spring, the is most naturally obtained by raising the little finger, as the is produced in the same order by raising the third finger from the ninth or A hole. And as these two fingers, whether raised separately for half-tones, or together for whole tones, always have a similar,

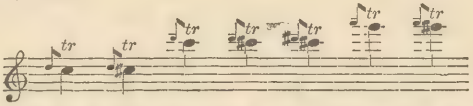
never a contrary movement, this action will be found, after a little practice, much easier, and more convenient in every kind of passage, than that with a shut G sharp key.

The B flat hole following the A hole is also encircled by a ring, which is fixed to the axle of the B key. Like the G key, this rises by its own spring, when the second finger is raised, and produces the note . To obtain the preceding note therefore, the B hole must be closed by means of the lever reaching as far as the ring-key that is closed by the first finger of the right hand. By this contrivance it will be seen one more finger is made up for by a ring-key.

The next note is produced by opening the key of the double C hole, which is closed by the thumb, and by opening the key of the C sharp hole, closed by the first finger. From the fingering of the lower octave or fundamental notes is repeated, with this difference only, that the C sharp hole is open for and as a vent hole, by which we pass with more ease and certainty into the octave.

For the higher notes which follow, the fingering of the lower or fundamental octave must be used; opening at the same time for each note the fifth hole above, as a vent hole. This is also the hole of the perfect fifth below, and by opening it, the notes become free in tone and more correct in intonation. Thus, for  the G sharp hole is open, for the A hole, and for the B flat hole; but for owing to the contrivance of the keys, the B hole opens of itself, when the second finger is raised from the B flat hole. For

the C and C sharp holes serve in succession as vent holes; the G sharp, however, sounding more freely if the C hole is open at the same time. As the C sharp hole has to serve as vent hole for  as well as for it must be removed from its natural place and made smaller, in order better to suit all these notes. On this account the lower F sharp and G holes have to be closed by the first finger of the right hand, with the fingering of A, the C sharp hole serving at the same time as vent hole. Finally, the last or D hole, stopped by a closed key, which by means of a long axle is worked by the second finger of the right hand, serves (the C sharp hole being also open) as vent hole for By it likewise seven shakes may be conveniently made.



Besides these keys, I also made a lever by which the C key may be closed by the third finger of the right hand, and thus this finger may be used for the shakes B flat with C, and B with C.

To obtain a steady hold of the instrument, and a free and easy movement of the left hand, I applied a movable crutch to the flute, by which its whole weight rests on the cavity between the thumb and forefinger of that hand. Lastly, to fill up the space which arises upon lengthening the flute in order to flatten the pitch, I made use of several rings, to be used in lieu of the metal sliding tube generally adopted; I rejected the latter, on account of the unequal and disturbed vibration which arises from the close combination of the metal with the wood, producing, to my ear, a disagreeable hardness of tone.

With this my labours terminated. I found further essential improvements impracticable, without the application of very complicated mechanism; nor did I consider it necessary, inasmuch as

the tone and intonation of my flute were greatly improved, while its key-mechanism rendered practicable the execution of every possible combination of notes.

These explanations are, I trust, sufficient to prove that this my invention is not a plagiarism, or work of chance; but the result of ripe meditation and practical experience. And if further proofs of my title to it were wanted, I can cite many respectable persons in Germany and elsewhere, to whom I had communicated my ideas long before their execution.*

Whatever has been done after the year 1832, be it for mere alterations, or real improvements (which I leave others to decide), I had no part in it; having been, till 1846, occupied in a very different manner. Besides, but for the repeated appeals made to me, I should scarcely have considered it worth while to claim the authenticity of my invention, for all the discussions on this subject refer merely to the key-mechanism, which is usually judged of by individual views, each one thinking that the best which best suits his taste or fingers. I only valued my own system of fingering so far as I found in its contrivance the most simple means for the attainment of my object, which was the improvement of the flute in its acoustical proportions; for *this* is the chief foundation of the higher or lower degree of perfection in all instruments, their mechanism being but of secondary importance. It is also much easier to construct keys than to improve notes. By my former experience in instrument making, I was fully aware of the causes of the defects of wind instruments, and I obviated them, for the most part, on my flute by the application of mechanical means.

Nevertheless, I was still in obscurity about many phenomena connected with acoustics, as my former labours were not founded on those special theoretical inquiries which I have lately been enabled to make. Last year, however (1846), I recommenced instrument making; and I began, for the instruction of my sons, with a close inquiry into the acoustical principles that are involved in the construction of a musical instrument.

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* See Dr. Schafhäutl's letter in the Appendix.—W. S. B.

From this source only could any further essential improvements of the flute proceed; for although flutes were made long before science endeavoured to point out how their tones were produced, yet it is certain that they can never reach their utmost perfection unless the maker has some knowledge of, and attends to, nature's invariable laws in the matter of proportion and substance.

Wind instruments, especially those having finger and key-holes, and depending for their quality mainly upon the accuracy of exceedingly complicated proportions, can only be brought near perfection by a strict application of the principles of acoustics in their construction. It is only when theory and practice go hand in hand, that, by the examination of the causes of the good as well as of the bad in existing instruments, the way can be shown for improvements which must otherwise be left to chance. The higher branches of mathematics have, from time to time, been applied to the investigation of subjects connected with acoustics, and the most learned men have endeavoured to develop and establish the laws of that science. D. Bernouilli, L. Euler, Poisson, Lagrange, and Lambert, as well as Biot, Chladni, Savart, and many others, have calculated and explained the proportions of vibrating columns of air, and have given us the results of various experiments. Their observations, however, threw but little light upon the true nature of wind instruments. For the conclusions arrived at by mathematicians are much too general to give data practically applicable to the construction of our musical instruments. In such inquiries it is absolutely necessary that the natural philosopher should also be both a musician and a mechanist. This is probably the reason why, as I believe, with the single exception of "The theory of covered conical and cylindrical tubes, and German flutes," published in Germany by Dr. Schafhäutl, under the name of C. E. Pellisov, in Vol. VIII. of the "Annals of Chemistry and Physics," no essay on the theory of flute-making has been written, in which the nature, extent, and combination of the special phenomena on which our German flute is founded, have been explained in what concerns lineal and vibrational proportion. In this little extract of a lecture on the above-mentioned subject, the theory was simply applied to the fife, or the cylindrical Swiss pipe.

A conical flute could not be constructed according to the principles laid down in this work, unless they were explained in greater detail; but to an instrument maker already well versed in acoustics, it gives a foundation on which he may pursue his way with security. By continual attention to Schafhäutl's observations, and by my own experiments, I have obtained, of late especially, much more satisfactory results; so that at length I have very nearly ascertained the true theory.

As the communication of these results might be less intelligible without a knowledge of the principles of acoustics upon which they are founded, a simple explanation of them, as far as necessary, may be welcome to those who are not acquainted with the accurate proportions of a German flute.

In order to obtain the sound of a wind instrument, the column of air within the tube must be brought into certain vibrations, different from those of strings, tuning-forks, or metallic springs. These vibrations must re-act upon the body that surrounds the air-column, and excite its molecular vibrations, without which no sound can arise.

It is therefore necessary, above all things, to gain an acquaintance with the proportions of these vibrations. The simplest means of convincing one's-self by ocular demonstration of the pulsatory motion of a column of air within a tube or apparatus, is Hopkins's apparatus. (Fig. 4.) This consists of a glass tube about two feet long and one and a half inches in diameter, which is fixed perpendicularly into a metal ring lined with cloth, in such a manner that close beneath the tube, a metal plate or tongue, like the æoline, may be screwed, and sounded by means of a violin bow.

There must also be a ring of smaller diameter than the glass tube, covered with a very fine membrane, like a drum, to which three fine silk threads are fastened, so that it may be held like a scale.

To be able to make an experiment with this apparatus, it is requisite that the tongue be tuned to the same sound as that given by the glass tube. If the tongue be then sounded by means of the bow, the air contained in the tube is affected by the motion

of the tongue; and as the same note will be produced by the tube, not only the number of vibrations must be necessarily the same, but the motion of the column of air will be also communicated to all bodies capable of similar pulsations, and coming within its influence. Thus, if the little drum, strewed with fine, dry sand before, is let down into the tube while the sound is clear and pure, the following phenomena will result:—

As soon as the drum is placed above the border of the sounding tube, the sand on the membrane begins to skip, so that part of it is thrown down. As the drum is gradually let down into the tube, the height to which the sand is thrown becomes gradually less, until at last, when we have reached the middle of the tube, it remains almost motionless. Beneath that joint the sand begins to move again more, and this motion increases the more deeply the drum is inserted, until at the lower end of the tube the sand is again thrown off the membrane with the same force as when at the top. (Fig. 5.)

From this simple experiment it is evident the air has not the same motion in different parts of the tube, but that the vibrations are strongest at the two ends, and decrease thence gradually, until in the middle they are almost at rest. In this pulsatory motion the single particles of air move longitudinally from and towards one another in the direction of the axis of the tube. This is called *longitudinal* vibration in contradistinction to the vibrations of a chord or string, which move sideways, that is, to the right and left, called *transverse* vibration.

The particles of air move only through a very small space, and immediately return to their point of rest. But as they move rapidly, they oscillate like a pendulum, to equal distances on each side of the point of rest, yet always in the direction of the axis. Now if we represent to ourselves that these particles of air advance and recede again a little at the same time from the openings at both ends of the tube, we shall find that where they move in opposite directions, there must be a part where no movement at all takes place. If the particles of air enter the tube from both ends at once, they naturally come to a stand in the middle, and

the air at that point is in a state of condensation. If, on the contrary, the particles of air recede from the point of rest, there arises an expansion of the air, where before there was the greatest condensation. The chief motion of a column of air under such circumstances consists, therefore, in an alternate condensation and expansion of the air at those points where the particles of air have the least motion—that is, in the centre; but at both ends of the tube, where the particles have the greatest motion, there is neither condensation nor expansion.

All those points where the air is at perfect, or nearly at perfect rest, are called, in the language of acoustics, *nodes* of vibration; and the portion of air vibrating between two nodes or points of rest is termed a settled wave, in contradistinction to the progressive undulations which transmit the tone through the air outside of the tube, and without which the settled wave within could not be produced.

Further, if we produce the octave of the fundamental note in the glass tube by means of a tongue tuned to the octave, and place the drum strewed with sand about the mouth of the tube, the sand will begin to skip as at the first experiment, and will be partially thrown down. But if we insert the drum deeper in the tube, the motion of the sand will decrease much more rapidly than in the first experiment; and when it has reached about the fourth part of the tube, the sand comes to an almost perfect state of rest. If we then sink the drum still more, the sand begins to move again, and when it has arrived at the middle of the tube, where in the first experiment the sand was at perfect rest, it dances with the liveliest motion. By proceeding beyond the middle downwards, the motion of the sand again decreases, until at the last fourth part of the tube it comes to the same state of rest as at the first fourth part; while beyond the last fourth part, and towards the lower end, the motion increases again, until at the lower extremity there is the same violent motion as there was at the upper. From this we see that in the second octave two points of rest or nodes are formed, each distant a quarter of the whole length of the tube from one of its ends.

Between these two nodes there is, therefore, a second and clearly

defined entire settled wave, which has its centre or point of greatest vibration at the middle of the tube; whilst the first is pressed towards both ends of the tube by means of the new one coming in between, and is thus divided into two halves, so that, if the two ends were combined, they would form a settled wave of the same length as the middle one. (Fig. 6.)

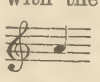
If we pursue these experiments still further (Fig. 7), three nodes are formed by the fifth of the octave, the extreme two of which are distant $\frac{1}{6}$ of the length of the tube from either end; with the second, or super-octave, arise four nodes, the two farthest being distant $\frac{1}{8}$ of the whole length from either end; and upon narrow uncovered organ pipes, on which, as is well known, the nodes are formed in the same manner, still higher tones may be produced, involving the formation of even 5, 6, 7, and 8 nodes.

Upon a closer view of the numbers of these vibrational nodes, we see: (1) That they appear in the natural arithmetical progression of numbers: and (2) that this natural progression of numbers expresses the proportions of the vibrations of one note to another Thus, for instance, if 1 represents the fundamental note C, with 260 vibrations of the column of air in a second, 2 represents the octave, the condensations and expansions produced being twice as many—viz., 520 vibrations in the same time. The fifth of the octave requires consequently three times, and the super-octave four times, as many vibrations in the same given time. We know also that the column of air in a sounding tube, according to the laws of equilibrium, only divides itself into portions of equal length. If, for instance, four nodes are formed, the undulations are consequently but half as long as they would be, if two nodes only were formed in the same tube. And from this again it follows that the vibrations are slow or quick in proportion as the undulations are long or short. An undulation half the length of another, therefore, vibrates with exactly twice the rapidity. The octave is thus formed by double the number of vibrations required for its fundamental. We can, however, obtain this octave in another way. Instead of dividing the column of air, by the force of breath or wind, into two undulations half the length, and vibrating with double velocity, suppose we

cut the tube into two halves at the middle, one undulation only is then produced, shorter by one half, and vibrating therefore with double the rapidity of the original air column. By this means the octave obtained before by the whole length of the pipe becomes the fundamental note of the pipe half as long. And from this proceeds again the theoretic law, that the number of vibrations corresponding to the pitch of a note varies inversely as the length of tube.

We may also obtain the original fundamental note, which was an octave lower, without joining on to the tube again the half that was cut off. This is done by closing the pipe at its extremity with a cover. In this case, as the air blown in at the labium of the pipe cannot escape at the lower end, the undulation is reflected from the bottom of the pipe, and returns to the upper end; and its vibrations becoming thus twice as long and only half as quick as they were before the tube was closed, the fundamental note an octave lower is the result—namely, the same note that was at first obtained from the whole length of the unclosed tube. A tube closed at one end, or as it is called a covered (stopped) tube, is, therefore, in regard to pitch, equivalent to an open tube of double its length.

Further, the actual pitch of every musical sound is determined by a certain number of vibrations. This number always remains the same for the same note, and may be determined exactly by calculations and measurement with the help of the Syren, invented by Caignard de la Tour; or by Savart's dented wheels, and other contrivances; or, more recently, very accurately by H. Scheibler's tuning-forks, in conjunction with the metronome.

According to Scheibler, the  of the Conservatory of Paris had 868.7, that of the orchestra in Berlin 883.25, and that of Vienna 881.74 oscillations in a second. The rapidity of the oscillation of this note being determined, the number of vibrations of all the other notes are easily calculated, the relative proportions of the intervals of the other notes having long since been fixed. As the length of strings decreases in proportion to the increase of the number of vibrations, $\frac{8}{9}$ of the string requisite for the production of

C gives D, $\frac{4}{5}$ E, $\frac{2}{3}$ G, $\frac{3}{5}$ A, $\frac{15}{15}$ B, and $\frac{1}{2}$ C gives the octave. For wind instruments, which are used in the orchestra and in all keys, the purely mathematical scale, as is well known, cannot be used, because the notes forming it have proportions different from each other. Consequently, the octave is divided into twelve intermediate geometrical proportions, of which the first is to the second exactly as the second is to the third, &c., &c. This is called the *equally tempered* scale, on account of the conformity of the several parts to each other. The following table shows the absolute and relative numbers for length of string and number of vibrations in the chromatic scale of equal temperament, assuming to be produced by 880 oscillations.

Lengths of Strings.		Number of Vibrations.	
		Relative.	Absolute.
C	1.000,000	1,000.000	523.25
♯C / ♭D	0.943,874	1,059.463	554.39
D	0.890,899	1,122.462	587.33
♯D / ♭E	0.840,896	1,189.267	622.26
E	0.799,701	1,259.921	659.26
F	0.749,154	1,334.840	698.46
♯F / ♭G	0.707,107	1,414.213	739.99
G	0.667,420	1,498.306	783.99
♯G / ♭A	0.629,961	1,587.400	830.62
A	0.594,601	1,681.793	880.00
♯A / ♭B	0.561,230	1,781.796	932.34
B	0.529,730	1,887.745	987.77
C	0.500,000	2,000.000	1,046.51

As in the works of natural philosophy it is assumed that the volume of the column of air has in musical wind instruments no essential influence on the pitch, the lengths of strings indicated ought to correspond to the lengths of the columns of air requisite to obtain the same notes.*

From a series of examinations lately entered into by Prof. Schafhäutl in regard to the influence of the diameter of the column of air, it is established that every pipe which is shortened does not give the sound corresponding to its abridgment according to the calculation for strings, but a lower one; because the diameter of the tube remaining unchanged while its length is diminished, the effect is as if the diameter of the tube had been increased.

From the same experiments it appeared that, if a tube closed at one end be used, the divergence from the calculations which hold true for strings will be still greater than if a tube open at both ends were employed; that is, the sound obtained will be flatter in proportion to the diminution of length.

Though the proportionate vibrations of a column of air, partly or entirely surrounded by a conical tube, are based on the same principles, the cone gives rise to some remarkable modifications. Of these the theory of covered tubes, very much enriched by the investigations of Dr. Schafhäutl, gives a full explanation.

It is known that a cylindrical tube, when covered at one end, will give a sound lower by an octave than that given by a precisely similar tube open at both ends.

If in the cover of this cylindrical tube a small aperture be made, and gradually enlarged, it will be found that the sound given by the tube rises in direct proportion to the enlargement of the aperture; and thus it may be shown that the reflection of the column of air from the cover of the cylindrical tube is in an inverse ratio to the size of the aperture in the cover. The same author has stated that a cylindrical tube terminating towards one end by a cone may

* I could, however, never persuade myself of the truth of the above-mentioned statement, since all wind instrument makers know very well that the pitch of a wind instrument depends partly upon the diameter of its tube.—T. Böhm.

[This has since been proved and demonstrated by A. Cavaillé-Coll, the organ builder, with regard to organ pipes.—See *Nature*, Aug. 7, 1879.]

be considered as a cylindrical tube covered at one end, and having in its cover an aperture, the diameter of which bears the same proportion to that of the tube as the aperture at the smaller end does to that of the larger end of the cylindro-conical tube. (Fig. 8.)

As with conical columns of air, a lesser volume has to be put in vibration than with cylindrical ones of the same diameter, it follows that conical pipes emit the sound more easily, but at the same time that the tone loses in strength in the proportion in which the diameter of the pipe diminishes; wherefore conical pipes are the only ones used for the soft-sounding registers of the organ.

It is further known, from Dr. Schafhäutl's experiments, that the part of a column of air in a wind instrument below a lateral or finger-hole exercises an influence only partially proportionate to its length; and must therefore be considered and calculated as a shorter column, and shorter in the proportion which the diameter of the finger-hole bears to that of the tube and to the length of the air column.

From the same experiments it results that the finger-holes must be considered as little tubes of the same length as the thickness of the wood, and also that the embouchure of a flute may be considered as a finger-hole, the quantity of tone remaining the same whether the flute be played at the embouchure or at the finger-hole.* The portion of tube from the centre of the embouchure to the cork, when rightly placed, must be reckoned double, because it forms a covered pipe, and counteracts the sharpening influence exercised by the embouchure on the pitch, which thus remains the same as that obtained by blowing into the orifice of the tube when without cork or embouchure.

Thus far supported by the general acoustic laws and special theories, I recommenced the investigation of acoustical proportions in wind instruments, and made a great many experiments, the results of which I will communicate concisely, as far as they relate to the flute.

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* Böhm's words are here given without alteration.

As the acoustical proportions of a cylindrical column of air must be the basis of all the calculations requisite for the construction of a flute, I first made a number of cylindrical wooden tubes of different lengths and diameters, in order to find out the modifications which arise from blowing laterally into the embouchure. But on account of the instability of wood, I never succeeded in obtaining reliable results; wherefore I resolved, after many unsatisfactory trials, to make all the models necessary for my experiments of metal. For the investigations of the proportions of length, where the quality of sound is not an essential point, thin hard-drawn tubes of brass of various diameters did me such excellent service, that I was able to perceive the most minute deviations in their proportions; hence my experiments attained great exactness.

After I had provided all my tubes with embouchures and stoppers, I sought the lengths corresponding to the diameters, by cutting off portions, until the fundamental note sounded with ease, certainty, and clearness. And as the diameters increased from 0.0328 ft. to 0.0984 ft. (10 to 30 millimetres), and the lengths from 0.82 ft. to 4.92 ft. ($\frac{1}{4}$-$1\frac{1}{2}$ metre), I found many fundamental notes within the compass of two octaves, viz., from down to the lower C of an organ pipe 4 feet long. The sound, however, of these notes up to was weak and hollow; and all the higher notes proceeding from the aliquot parts of the column of air were too flat. From these defects were less perceptible, because the embouchure, which would have been too large for playing upon if made of a size corresponding to the diameter of the long tubes, was of the right size for shorter and narrower tubes, so that the vibrations could be completely excited.

Convinced that tubes entirely cylindrical could not be used for German flutes with the fundamental note , but that, in order to obtain a free tone and correctly tuned octaves, the conical form must be made use of, I began to examine the proportions of the cone. I changed or lengthened alternately the base or the apex of the cone, which brought advantages or disadvantages; but, upon the whole the results of these experiments, although highly in-

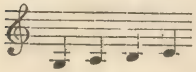
structive, were not important enough to be more particularly mentioned here.

Now, as there was very little to be improved in the conical shape employed towards the lower end of the flute for more than 100 years, I reversed the proportions by putting the cone in the upper part of the tube, and executing it in very different dimensions. I had made a few similar experiments thirty years before without success. After several fruitless trials, first with wooden and then with metal tubes, I thought I should have been obliged to give up, this time also, the realization of an idea which I had never entirely discarded since I made my first flute. I was always at a loss to understand why the flute alone should be played at the wide end, while all other wind instruments of conical proportions are played at the narrower end, especially as the latter method seems more in accordance with Nature; for while the sections of the air-column decrease in length as the pitch rises, so they also decrease in diameter. The reverse of this is the case with the conical flute, in which the cone is continued beyond the lower holes.

As the fundamental note of those tubes sounded best in which the cone, as now applied by me, reached from the stopper nearly to the uppermost hole, and as, on the contrary, the highest notes were improved by shortening the cone and lengthening the cylinder, there was naturally a medium best suited to these opposite requirements. And further, as according to theory a curved line is most suitable for the gradual contraction or enlargement of an instrument, I made at the upper end of my tube shorter or longer contractions, which in the outline of their form approached the "parabola," and which terminated in, or converged to, a hemisphere.

At length I obtained a head-piece, by means of which, on a cylindrical tube 0.0787 ft. (24 millimetres) in width, and without side holes, I could produce the low E of the clarinet, and when the stopper was moved a little, all the harmonics; whence it appeared that all the natural tones of the horn and trumpet can also be produced on a flute-tube, if it is long and narrow enough for the division of the column of air into the requisite aliquot parts. But as the low E, though easily sounded, was weak in tone, I

shortened the tube until the sound became powerful and perfectly clear, by which I obtained F as the fundamental note. After having applied these proportions to different lengths, always placing the stopper at about the $\frac{1}{27}$th part of the whole length of the column of air, I at last obtained the fundamental notes



with a very perfect tone.

With these results I ended my investigation of the proportions of the column of air best suited for the development of the fundamental notes; and from the experiments made thus far it appeared:

(1.) That the strength, as well as the full and clear tone of the fundamental notes, is proportional to the volume of air put in motion.

(2.) That simple vibrations can be most perfectly excited in large tubes having a contraction at the embouchure.

(3.) That every modification in diameter or length of this contraction has a great influence on the emission and intonation of the aliquot parts.

(4.) That this contraction must not be made in straight lines, but in curves.

(5.) That, moreover, the divisions of the columns of air into aliquot parts, or the formation of vibrational nodes—in short, all phenomena which appear in a vibrating column of air—are exhibited in a cylindrical tube in the most perfect and easy manner; consequently that a cylindrical tube is that best adapted for the construction of a flute.

(6.) That cylindrical tubes with the cone, as applied by me, at the upper end may be considered as entirely cylindrical; since the influence of the cone on the pitch is so insignificant, that in a tube with the fundamental note C it scarcely occasions a difference in length of 0.00492 ft. ($1\frac{1}{2}$ millimetres).

As, then, the dimensions that correspond best to the formation of the fundamental note are also the most nearly in conformity with theory, a flute constructed according to such proportions, and with a compass of two octaves, would certainly be the most perfect in regard to fulness, purity, and freedom of tone; but in order to

extend the compass to three octaves, as is required at the present day, I was obliged, for the sake of freedom of tone in the upper notes, to use narrower tubes, and thus again to injure, in some measure, the finest notes of the first two octaves. A second obstacle which obliged me to deviate from theory was the impossibility of making the distance of the stopper from the centre of the embouchure proportional to the lengths of the several undulations of air, unless by mechanism, the making of which would present almost insuperable difficulty.

A medium place for the stopper must therefore be found, by means of which the vibrational nodes of the upper notes may be prevented coming too near the embouchure, so that the development of these notes may still be secured.

By several trials, made as accurately as possible, I found that the proportions most suitable for obtaining good and pure tone throughout the compass of a flute with the fundamental note were as follows :—

		Foot.	Metre.
(1.) Length of the tube from the stopper to the end of the flute	=	1.984	0.606
(2.) The 1-32nd part of this length, as best suited for a medium diameter of the cylinder	=	0.062	0.019
(3.) Reduction of that width by the conical contraction, beginning at the upper sixth part of the whole length of the tube, and being at the middle of the embouchure ..	=	0.0065	0.002
(4.) Medium distance of the middle of the embouchure from the stopper ..	=	0.055	0.017

Further, I made some experiments as to the embouchure, its form and size being of the greatest importance. The current of air by which the tone is produced must always be blown at an angle proportionate to the height of the note towards the upper

border of the embouchure, which breaks, or rather divides it, so that part of the current of air passes over the hole; but the greater part—especially with a good embouchure—produces tone, exciting the column of air enclosed in the tube, and putting it into undulating vibrations, much in the same way as the string of the violin is put into transverse vibrations by the passing over it of the bow at right angles. By the undulations of air the molecular vibrations of the surrounding tube are also excited, and the result is tone, which lasts as long as the supply of vibrating air is maintained.

The strength of the tone will be proportionate to the quantity of air set in vibration within the tube; and as the aperture between the lips through which the air passes into the embouchure is in the form of a slit, a long-shaped quadrangular embouchure, with rounded corners, which presents a wide edge to the broad pencil of air, must be better adapted to take in a large quantity of breath than an oval or round hole of equal size. For the same reason a larger embouchure will produce a stronger tone than a smaller one. A large embouchure, however, requires greater strength in the muscles of the lips, because it leaves a hollow space beneath the lip, which is therefore unsupported, and it becomes difficult to direct the current of air at the proper angle. Upon this depends not only the intonation of the notes, but also their quality; the tone becomes flatter, more confined, when the breath is directed downwards towards the centre of the embouchure; sharper and more hollow when the breath is directed towards the circumference. Consequently the angle formed by the sides of the embouchure, as well as the height of these sides, has great influence on the freedom of tone. In my opinion an angle of 7° is that best suited to the whole compass of notes, the sides having a height of 0.0137 ft. (4·2 millimetres), and the size of the embouchure being 0.0393 ft. (12 millimetres) in length to 0.028 ft. in breadth.

These proportions I think best adapted to most flute players.

On a flute-tube made after these designs the fundamental note C sounded with the slightest breath, notwithstanding that the stopper was removed from its theoretically correct place; it admitted also

of being very strongly blown without rising in pitch, and the hissing noise so perceptible on other flutes was not heard. This served to prove to me that, owing to the accurate dimensions of my tube and its very smooth inner surface, the undulations of air were formed without any noticeable friction. Hence, as well as from the fine tone of all the aliquot parts, I concluded that the tube I had now obtained was the one best adapted for a flute. I began, therefore, to find out the divisions of the column of air. The shortest and most simple mode of obtaining all the notes of the first octave is naturally that of cutting from the lower end of the tube, until the new fundamental note produced by each section answers to the pitch of the note sought for and shown by tuning-pipes, tuning-forks, or a well-tuned piano ; then the ear decides as to the accuracy of the result.

Theory indicates a much surer, but also more troublesome method. If, as Schafhäutl has shown, the stopper is so placed that the fundamental note given by the whole length of the flute appears perfectly correct, the tubal sections for the remaining notes follow the same laws as those which determine lengths of strings. It is therefore easy to find by calculation the notes of the first octave, either in their natural or their tempered proportions. As the influence of the contraction of the upper part of the tube is the same upon all the notes, and need not therefore be taken into account, this calculation is made in the most simple manner, and with an accuracy sufficient for the practical construction of instruments, in the following way:—The constant length of the tube from the lower end to the centre of the embouchure being 1.9324 ft. (589 millimetres), and the distance of 0.0771 ft. (23.5 millimetres) from the stopper (when in its theoretically correct place) to the centre of the embouchure being counted double (because that part is considered as a covered pipe), the whole length of the assumed column of air is then: $1.9324 + (0.0771 \times 2) = 2.0866$ ft. $= 589 + (23.5 \times 2) = 636$ millimetres.

The sections of this assumed column of air bearing the same proportion to its length as the number of vibrations bear to the different lengths of strings, the lengths of the columns of air, corresponding

to every note, may be easily calculated by reference to the table given above, and to the formula:

$$\begin{array}{c} (1.000{,}000) \quad (0.943{,}874) \quad (2.0866 \text{ ft.}) \\ C \quad : \quad C \text{ sharp} = l \quad : \quad x \\ (1.000{,}000) \quad (0\,943{,}874) \quad (636 \text{ m.m}): \\ C \quad : \quad C \text{ sharp} = l \quad : \quad x \end{array}$$

From the ideal lengths obtained by these calculations, the portion of 0.0771 ft. (23·5) m.m. must be again deducted, in order to obtain the real lengths from the stopper to the lower end.

Therefore the length of the tube at the second C, or the octave of the fundamental note, is—

$\frac{2.0866}{2} - 0.0771 = 9662$ ft. $= (\frac{636}{2} - 23{\cdot}5) = 294.5$ millimetres.

But as the stopper, to suit the entire compass of the flute, must be moved towards the centre of the embouchure, so as to be at a distance of only 0.0557 ft. (17 m.m.), the real length of the tube for the octave C is, after the deduction of this difference:

$(\frac{2.0866}{2} - 0.0771) - 0.0214 = 0.9448$ ft. $= (\frac{636}{2} - 23{\cdot}5) - 6{\cdot}5 = 288$ millimetres.

For an exact examination of these proportions, I made a tube in which all the twelve sections could be successively taken off and put together again, by soldering together the calculated lengths of tube, and covering the joints with metallic rings, so that each length was joined hermetically to the preceding one.

I also contrived a sliding piece at the upper end of the tube, by means of which any fault of intonation could be accurately rectified.

The correctness of the calculations being proved by repeated trials, carefully made, I afterwards proceeded to the examination of the proportions of the holes.

As a flute cannot be made to consist of separate pieces, all the sections for the different notes must be united into one continuous

tube, and holes bored laterally must be substituted for actual disconnection. The column of air is to be considered as divided or cut off by the holes, in a degree determined by the proportion which the diameter of the holes bears to that of the tube. By the finger-hole, however, the column of air is not so much shortened as that the position of the hole corresponds exactly with that of a section; for the holes cannot be made of a diameter equal to that of the tube, on account of the difficulty of stopping them. And even if that could be done, the undulations of the air would not issue so easily from the hole at right angles to the axis of the tube as from the orifice of the tube in the direction of its axis. The undulations encounter the resistance which the column of air contained in the lower part of the tube opposes to them; and this resistance is so considerable when small holes are used, and are bored exactly at the theoretically correct points of section, that all the notes sound much too flat. Therefore the smaller the holes are, the nearer they must be moved to the embouchure. Thus, the pitch of a note does not depend solely upon the length of the column of air, but also upon the size of the hole from which it issues, and upon the size and distance of the holes next below. To fix the position of the holes for the chromatic scale, a certain size of hole must be decided upon; after which the points for their position may be ascertained by calculation.

Although one octave, at least, may be correctly tuned with small holes by shifting their position, it is still desirable to make the holes as large as possible, for the following reasons:—

(1.) The notes can only be developed with freedom and power when the holes are large, and bored as near as possible to their theoretically correct places.

(2.) When the holes are small and considerably out of their proper places, the undulations of air often come too near the nodes of vibration; and their formation being disturbed or rendered uncertain, the tone sounds with difficulty, or easily breaks into notes answering to the aliquot parts (harmonics.)

(3.) The smaller the holes are, the more irregular do the undulations of sound become; and, as a consequence, the tone loses power, clearness, and volume.

(4.) The intonation of the third octave depends chiefly upon the correct position of the holes.

From the experiments I made it follows that these injurious influences are only imperceptible when the size of the holes is at least $\frac{3}{4}$ the diameter of the tube.

Next to the diameter of the holes, the height of their sides, which form, as it were, little tubes branching from the main tube, exerts an important influence upon the intonation and tone of the notes. Whilst investigating these various proportions, I have tried, on pieces of a tube, holes not only of different sizes, but with sides of different heights, which I could at pleasure insert between the sections. On a tube of 0.0623 ft. (19 m.m.) in diameter the lowest or C sharp hole, 0.0393 ft. (12 m.m.) wide and without border, required, when correctly tuned, to be moved 0.0147 ft. (4.5 m.m.) above the section of the column of air calculated for that note. With an even border in height of 0.0032 ft. (1 m.m.) a removal of 0.0188 ft. (5.8 m.m.) was required, and with a border in height of 0.0099 ft. (3 m.m.) the removal amounted to 0.0259 ft. (7.8 m.m.); from which it appears that the distance of removal increases almost in the same ratio as the height of the side of the hole, and its extent depends upon the proportion which the diameter of the finger-hole bears to the diameter and length of the tube.

The flattening influence of the column of air below the sounding hole, which causes at the last section of 0.1171 ft. (35.7 m.m.) in length a removal of 0.0188 ft. (5.8 m.m.), increases at each new section. Therefore the D hole must be already removed 0.0219 ft. (6.6 m.m.) above the theoretical section, and at the octave of the fundamental note C the requisite removal amounts to 0.0410 ft. (12.5 m.m.).

But since, as already mentioned, the distance of removal increases in proportion to the length of the sections, it is sufficient, when fixing the position of the holes for the chromatic equally-tempered scale from the fundamental note C up to its octave, to place these two C holes according to the given calculation, and then, after having doubled the length which separates their centres, to calculate the intervals by the method applicable to strings, as has been shown above.

If, for instance, the fundamental note C is produced by a hole in a tube lengthened to the B below, the centre of that hole comes to a distance of 1.9714 ft. (601 m.m.) from the stopper; and further, the distance of the centre of the octave C hole from the stopper, being reduced by the necessary deduction of 0.0413 ft. (12.5 m.m.), on account of the flattening influence of the holes, from 0.9448 ft. (288 m.m.) to 0.9035 ft. (275.5 m.m.), the length of tube between both centres is 1.0679 ft. (601 — 275.5 = 325.5 m.m.).

This length taken double, the length of the assumed column of air is:

$$1.0679 \times 2 = 2.1358 \text{ ft. } (325.5 \times 2 = 651 \text{ m.m.}).$$

This length considered as the length of a string, the C sharp is obtained according to the above-mentioned formula:

$$\begin{array}{ccccc} (1.000{,}000) & & (0.943{,}874) & & (2.1358) \\ \text{C} & : & \text{C sharp} = l : & & x. \\ (1.000{,}000) & & (0.943{,}874) & & (651) \\ \text{C} & : & \text{C sharp} = l : & & x. \end{array}$$

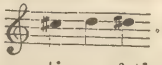
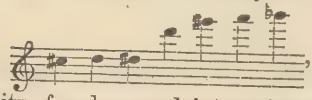
And by substituting successively the calculated lengths of strings, all the intervening intervals are obtained.

If, further, the 0.1630 ft. (50 m.m.) added to the real length of the flute tube for obtaining the assumed length, are again deducted from the calculated lengths, the remainder gives the exact distance from the centre of the holes to the stopper.

By these calculations I obtained all the tones of the first octave very correctly, and with large holes of uniform diameter. It was then easy to fix the notes following above and below for the second octave. These notes, however, as well as those of the third octave, require no additional holes. In every tube of a certain length, not only one, but two, three, four, and even more vibration nodes are formed, which give the upper octaves in the same sequence.

This is effected either by blowing harder, or by narrowing the opening of the lips, and changing the angle at which the breath is

directed, causing in both cases a quicker current of air to pass, and consequently producing shorter undulations.

But as it is necessary, in order to obtain a greater compass of notes, to make use of narrower tubes than those best suited to the fundamental note, these latter are too narrow in proportion to their lengths up to the section of D sharp. And the first three notes of the second octave after C  have a different *timbre* up to E, where the correct proportions of the tube, and with these the clearness and power of that and of all following notes, are restored. Therefore a flute ought to have three additional holes, corresponding to the others in size and position; not only in order to retain equality and identity of *timbre* from the second C to the second E, but also on account of the higher notes. As these three holes are designed by theory to be vent-holes in octaves and fifths for  , all these notes would gain in quality, freedom, and intonation, if the additional holes indicated were used.

But without again changing my system of fingering of 1832, now so much used, I was unable to use the calculations for these three holes, as only one finger was still available, and that was wanted for the C sharp hole; therefore I was obliged to ascertain by experiments the size and position of a hole which should offer the best compromise. For this reason the C sharp hole, as well as those above, had to be removed far beyond their correct position, and to be made smaller in proportion.

For an exact examination of these, as well as the tuning proportions in general, I made a model flute with movable holes, by which I was able to tune all the notes higher or lower at pleasure.

Although I could in this way easily find out the best position and size for the upper three holes, it was not possible to obtain the tuning of the other notes so perfectly by ear as I had done by calculation; for in endeavouring to produce in one key an entire pure scale, the notes were always thrown out of the proportions of the equal temperament, without adhering to which the

best possible tuning proportions cannot be obtained on wind instruments with finger-holes.

From these examinations, followed up with perseverance, I at last obtained a model flute, on which all the notes sounded not only fuller and more powerful than on any other flute, but they were also capable of every modification of tone from the loudest *forte* to the softest *piano*, without losing quality or sinking in pitch; and as, moreover, they sounded with the greatest freedom and the most perfect intonation when they were blown in the most natural manner, the performance was rendered more easy, more certain, and more correct than on other flutes, which require for nearly every different note a different embouchure. (Fig. 9.)

After the acoustical proportions were thus satisfactorily arranged and fixed, I examined the influence of different metals on the quality of tone. The metals which have comparatively little elasticity gave the softest, but at the same time the weakest tone; tubes made of very hard German silver gave, on the contrary, a clear but shrill tone, and silver and brass tubes yielded the best tone in every respect.

Compared with their notes, the tone of flutes made of wood sounds literally wooden; and if the tubes are very thin and hard drawn, by which the elasticity, and therefore the capacity for the vibration of the metal, is remarkably increased, the tone of the flute is exceedingly delicate and free, as well as extremely sonorous.

The superior excellence in regard to tone and intonation of my flute, made entirely of silver, when compared even with my newly constructed one of 1832, was so striking that it was remarked by every one immediately. These metal flutes are not subject to splitting, they cannot vary in the bore, and require neither to be oiled nor to be frequently played, but they always sound equally well. And even temperature affects them less than wooden flutes, because the metal, being an excellent conductor of heat, reaches its highest possible temperature in a few seconds, so that the pitch cannot rise any higher.

The acoustical proportions for a flute being now exactly ascertained, and given in numbers, it is not difficult to make

perfectly tuned flutes, be it flute d'amour, concert flute, or octave flute of any given pitch.

Messrs. Rudall & Rose, in London, who manufactured, many years since, flutes of my former constructions to the greatest perfection, are the patentees in England for my metal flutes; and I feel convinced that all who take interest in this invention, and play upon such flutes, will be as much satisfied with this improvement as I am myself.

THEOBALD BÖHM,

Königlich: Baierisch: Hofmusiker.

London, 1847.

BÖHM'S LETTERS.

Sept. 30, 1865.

To W. S. Broadwood.

I advise you to clean always the tube well after having played, but not with a usual cleaner, which is never fit to make the interior perfectly dry. You must take an old soft handkerchief of silk, and push it through the tube by means of a thin cane stick of the length of the middle piece. Don't forget always to take the cork out of the head-piece, that the handkerchief can pass throughout. The water adheres then to the first part of the handkerchief, and the following part, being still dry, will clean the boring well. And if you repeat that manipulation once or twice, the interior of the flute becomes soon to appear like polished, if you look through it; and the tone will increase in this way in clearness and easy emission. Further, take care that the cork on the two joints of the middle piece is always well greased with clean white tallow. If they go easy, you never risk an accident with the mechanism of the keys. You may give in the beginning some oil (*de Provence*) in the head-piece; but if you always clean your flute well, it is better without oil.

The middle piece and the foot *ought never to be oiled.* If you treat your flute in this way you avoid cracks in the wood, and also extensions, by which often the boring suffers, as all wood is liable to swell by the moisture. I have sent you one head-piece, two middle pieces, and three tubes for making feet, if Mr. Pratten should like to try also a foot down to B. The tubes are exactly like my silver tubes, only more than long enough, so that Mr. P. is at liberty to cut them as long as he pleases. I wish him a good success with all my heart; but if he changes much in the size or

situation of the holes, he will never get out something good. Pray give him my best compliments.

As to the material of which you write (ebonite), I have already made a flute of it about ten years ago. There was a flute and a clarinet of it at the Exhibition of 1851, sent by a man from New York. The inventor sent me afterwards enough cast tubes for two flutes for trying them. I made one flute, but was not satisfied with its tone. There was something dead in it, like a flute of ivory; and I have still the material for the other flute. No! Wood is the best of all.

As I cannot make a flute in G of wood, because it gets too heavy, I made the head piece of wood, and my flute gained a great deal in quality of tone.

It gave me great pleasure to hear that your brother Henry mentioned our discussions on pianos in 1851. If I could have lived with him, I think I could have been useful to him in many things. Pray give him my respects and compliments. I am now an old man, still capable of thinking, only my memory gets weak, and my health is not yet quite recovered. I had suffered too much this year.

Note.—Mr. Pratten having expressed a wish to try a silver flute, I procured for him, from Böhm, some tubes (those alluded to in Böhm's letter), and to these Mr. Pratten was to get holes and keys made, on the *Siccama* system, which he had adopted. Pratten did eventually try a silver Siccama flute, but it was not a success.—W. S. B.

Munich, *April* 19, 1866.

To W. S. Broadwood.

I have already said that I prefer the tone of a wooden flute, as quality, not quantity, is the first consideration for me as an artist. As long as I had the full command of my very good embouchure, I have always played on silver flutes; but when I had lost some of my front teeth, I was no more sure of a round sonorous quality in the metal flutes, particularly in the third octave, and then I began

to play on wood. There is no doubt that the tone on metal flutes is louder, more penetrating, or carrying further, than that of wooden flutes; and if a player has a full command over his embouchure, as I had till ten years ago, the tone is more brilliant, clear, and strong without harshness. But as long experience, with at least 100 pupils, has proved that there is scarcely one among twenty who has a perfect embouchure, and also the feeling for—or rather the patience to study—a good tone, I recommend always wooden flutes, which they can play better than metal flutes without a very good embouchure. Dorus, who played always on wood, plays, since 1855, silver flutes; and as he does it, his colleagues and pupils do the same. It is altogether a matter of taste.

MUNICH, *April* 28, 1866.

To W S. BROADWOOD.

You are much in error, if you believe that a metal head would have a good effect on a wooden flute. My dear Sir, all these sorts of things I have tried years ago! A metal head on a wooden flute is only fit to make the sonorous tone of it thin and harsh. The tone of a metal flute can be improved by a *wooden head*, in order to mollify the quality, as I did with my large flute in G, which has more power than necessary; but a metal head spoils the tone of a wooden flute. Who wants a strong, loud, ringing, and clear tone, should take a silver flute, with an embouchure of gold, which, standing free on the tube of the head, leaves the vibrations *most free*, and you feel it in your finger ends. But who has no *good* embouchure or tone on such a flute, and is content with a round and sweeter tone, though less loud, should take a wooden flute.

As to your question about German flute players, I am sorry to say there is not one like Dorus or De Vroÿe, if I speak of perfection in every respect.

There is, at Hanover, Mr Ott (a pupil of mine), who has the finest tone on his wooden flute, and great execution. There is Mr. Krüger at Stuttgart, also a pupil of mine, a very good player; and there are at Carlsruhe, Mannheim, and Coburg, also pupils of mine,

all very good orchestra players, and I think about as good solo players as your London players, with the exception of Mr. Pratten, whom I like very much. Mr. Wehner is at St. Petersburg. He is the only one who, till lately, played on a silver flute; now he also has a flute of wood. At Berlin and Vienna they play still on the old flutes. But at Frankfort is also a good player on my flutes, Mr. Kesewitz. As to fine taste, I consider Dorus and De Vroÿe as first; as to tone, Ott, Krüger, and several others are superior. When De Vroÿe had played here, many said to me: "De Vroÿe is a very fine artist; but if we remember your tone and playing, he seems little and weak in comparison." Our first flute player has more tone, and as much execution, but not the fine taste. I have now a pupil who promises to get on very well. As to playing in a grand style, I never more heard anything like Nicholson and Tulou. They play now much more, but less in quality.

(*From the German.— W. S. B.*)

May 20, 1867.

To Mr. W. S. Broadwood.

It results from the laws of acoustics that all wind instruments with a wide bore are fuller in the lower notes, while, on the other hand, those with a narrower bore are freer in the upper notes. The only question, therefore, is which you prefer. I have made several wooden flutes with a bore 20 millimetres in diameter— therefore one millimetre wider than usual; the first and second octaves were better, but of course the third octave was not so good. I could indeed still play up to C^3; but from $F\sharp^3$ upwards, the notes were sounded with difficulty, and if my lip did not happen to be in good order, I could not sound the higher notes, *piano*, at all.

The flute, whether in the orchestra or in solo playing, is treated as the next highest instrument after the piccolo; modern composers especially do not hesitate to write for it up to C^3, therefore the bore of 19 m. m. diameter is certainly the best for general purposes. Large holes are always better than small ones, for with them the sections of the air-column are more perfect, and the tone is developed better and more freely. Probably, no flautist or instrument maker

ever made so many experiments of all sorts as I have. Having been a professional musician, I was competent to give an opinion on what related to art; and as I was never satisfied until I had made myself thoroughly acquainted with the theoretical side of every question, I think I may venture to say that I know more than any of my colleagues, whom I have known either personally, or through their work.

In my pamphlet, "Ueber den Flötenbau und dessen neueste Verbesserungen" (Schott, Mayence, 1848), I have stated that even at that time I had already made experiments of all kinds with metal tubes, wide and narrow, thick and thin, hard or soft-drawn: of silver, German silver, brass, copper, and tin. But to get an easily sounding, vibrating tone, it is not enough that the head-joint should be thin and hard-drawn; the material of the whole flute must be similar in this respect. I know quite well why the instrument makers recommend thick silver tubes. It is because the difficulty of drawing the tubes increases in proportion to their thinness

Neither the English nor the French makers draw their tubes themselves; they have not the necessary machinery, and they can procure them ready made cheaper and with less trouble. I made everything myself; and despite all care and all precautions, it frequently happened that at the very last moment a tube would burst, or became crooked or oval, so that it could not be used. If I had not my pension, and depended wholly on flute making for my living, I must have let many things pass which were not of the best. For fourteen years I had as assistant a skilled watchmaker, to whom four years since I gave over my workshop. He is as honest as he is skilful. I never allow him to employ more than two workmen, because the object is quality rather than quantity.

Our firm will soon be known as "Böhm and Mendler." For if any one is to carry on the business after my death, according to my ideas, this, and no other, is the right man.

Your silver flute with two head-joints, one silver, the other wood, will be ready in a month at farthest. I have kept to the bore of 19 m.m. diameter; but the holes will be one millimetre wider, with such an opening as will admit of the freest development of

tone. The mechanism is the same as before, only that the B♭ key is so arranged that the C key always closes with it. The position of the holes also will be the same, as in the last flute, but the pitch will (as you wished) be sharper. This will be effected by the increased width (1 m.m.) of the holes, so that you may draw the head out about 2 m.m., and still play in tune. I will take care that the workmanship is as good and solid as possible.

You tell me that Mr. P. has two middle joints, one for normal, the other for sharp pitch, but only one foot-joint, used for both. But the intonation can only be correct for one of them (when the whole flute is put together). The difference of the calculated positions of the holes from E down to C is more than 5 m.m. Those who made the flute ought to have explained this, if indeed they themselves understood it.

The head-joint can only be used for either pitch equally, when it has been specially made with a view to that purpose. I took care of this in making the head of your present flute, so that you can at any time have a middle joint and foot-joint made to it at the normal pitch, if, as doubtless will be the case, that pitch is eventually adopted in England. In that case also my diagram would be useful for calculating new scales for pianos. On it you will find all the proportionate lengths given with mathematical accuracy.

Note.—The flute above described, made for me by Böhm with two head-joints, was, I believe, the first silver flute made with a wooden head-joint. Böhm was much pleased with the result of the experiment, and at a later date recommended wooden heads for silver flutes very strongly, especially for the silver G flute (alto).

I have lately had this wooden head fitted—as Böhm foretold—to a flat silver flute. The silver head and middle piece and foot are in the possession of Mr. T. Jones, of Ludlow.—W. S. B.

To W. S. Broadwood.

In a letter dated Munich, June, 1867, replying to some questions respecting the origin of certain improved processes in the manufacture of pianoforte strings, and that of the system of

diagonal (crossed) stringing, both apparently first suggested by Böhm, but carried out and even patented by others, he says:—

"If it were desirable and possible to analyse all the inventions that have from time to time been brought forward, we should find that scarcely in any instance were they the offspring of the brain of a single individual, but that all progress is gradual only; each worker follows in the track of his predecessor, and eventually perhaps advances a step beyond him. I was myself never at a loss for an idea, and have often helped others onwards towards success; it depends frequently on some mere trifle, which may not occur to a man's mind at the right moment. . . ."

Note.—Böhm also devised and sold in the North of England an improved method of manufacturing steel. He always showed himself very fertile in expedients, whatever might be the pursuit in which for the time he was engaged.—W. S. B.

Tegernsee, *Sept.* 23, 1868.

To W. S. Broadwood.

The difference caused by embouchure (viz., method of blowing) is so considerable that in many cases it amounts to more than a quarter, in some even to half a tone; therefore, in making a flute to any given pitch, it is not enough for me to know the number of vibrations; I must also have some knowledge of the player's embouchure. For instance, I have never yet met with a flautist who played as sharp as myself on the same flute, excepting Tulou, who was celebrated for the largeness of his tone. Dorus would have played a quarter of a tone flatter on the same flute.

The size of the mouth-hole, as well as that of the finger-holes, also materially influences the volume of the tone. For a large full tone a large mouth-hole is necessary. I could never play properly with small oval mouth-holes.

(*From the German.*)

MUNICH, *Nov.* 15, 1868.

To W. S. BROADWOOD.

Your letter gave me much pleasure, for the approval of one who understands the subject is always a satisfaction.

You see that, although nearly 75 years old, I have not relaxed in my endeavours to render my instruments as perfect as possible; and when you read my treatise upon the flute and its treatment, you will see that I have not made, or subsequently altered, anything without good and sufficient reason.

Thank goodness, I have at length finished it, and will see about a publisher. There ought properly to be both a French and an English translation; but I cannot myself undertake them.*

You wish to know the effect of shortening the head-joint.

As the proportions which determine the position of the finger-holes on any flute can only be quite accurate when based upon *one particular measurement* of distance from the cork, it follows that every diminution of, or addition to, this distance must influence the intonation prejudicially. Your new silver flute is so arranged that the proportions are quite accurate when the head is drawn out 3 m.m.; therefore you may also *shorten* the air-column by that much (thus sharpening the pitch), without very perceptibly affecting the intonation.

The C^1 will now become flatter, and the C^2 sharper, in the same proportion to the A^1; and if you pull out 3 m.m. more (therefore 6 m.m. in all) beyond the central (theoretically accurate) point, then, conversely, the C will be as much too sharp as the C^2 will be too flat. In the first two octaves this influence will be equal, but in the third octave a little different, on account of the vent-holes; for instance, E^1 is influenced only by its special finger-hole, E^3 is influenced in addition by the opening of the hole of A^1 the fifth above.

You will understand this perfectly if you read the enclosed explanation of my diagram attentively.† I drew out this diagram in order that instrument makers might form an accurate idea of the geometrical progression in which the position of the holes must be

* Die Flöte und das Flötenspiel. Aibl, Munich. † See page 66.

varied to suit different pitches. This diagram could only be designed by one who was at once musician, instrument maker, and skilled in acoustics. At the Paris Exhibition, unfortunately, the jurors, being unfamiliar with the subject, declined to go into it; wherefore, at the request of the Committee of the Bavarian Polytechnic Society, I had my diagram published in their "Kunst-und Gewerbeblatt." This work cost much time and trouble, without bringing me one penny of profit; nor did I receive anything for my pamphlet on the Construction of the Flute, of which Mr. Carte took possession.*

My treatise will contain chapters as follows:—

(1) Introduction, (2) The various kinds of Flutes, (3) Description of the Flute Tube, (4) The Material, (5) The System of Fingering, (6) Description of the Key-Mechanism, (7) Repairs, (8) Treatment of the Mechanism, (9) The Pads, (10) The Springs, (11) The Cork, (12) Treatment of the Flute, (13) The *Tone-Seasoning* of New Flutes (das Einblasen), (14) Study of Tone (Embouchure), (15) The Movement of the Fingers, (16) Exercises, (17) Style, (18) Table of Fingering, (19) Preliminary Exercises, (20) Examples illustrative of Style.

If to this were appended the explanations of theory formerly given (pamphlet 1847), and also the diagram, the history of all my work and all my experience, during a period of 60 years, would be contained in one little book. Perhaps it would be better to bring it out in two separate parts: (1) Theory, (2) Practice. Very few people understand anything about theory, and might not care to pay the additional price. What do you think? I should be glad to know, because I value your opinion highly.

NOTE.—The "pamphlet" alluded to is that now published with these letters. Mr. Carte tells me that it was given not to him, but to Mr. Rudall. The "Treatise" is published in German, but has not yet been printed in English. Böhm wished me to translate it.—W. S. B. (1882.)

MUNICH, *May*, 1870.

To W. S. BROADWOOD.

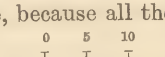
As you have already so many flutes, I should not like to make one more for you without being sure of everything. Therefore you must allow me to be somewhat particular in my requests,

* This is the pamphlet now published.

and I will try to be as precise as possible, if you will take the trouble to attend to them. All you require is a good ruler of the length of a flute, a compass, and a measure with millimetres. The millimetre is now universally used, as it is the fittest for measuring small parts, and the easiest for calculations in decimals. But if you do not like such things, I will try to be as clear as possible in another way. The question is, *how long* must be the tube of a flute from the *cork* in the head to the *end* of the foot, in order to obtain the C^1 exactly in tune with 529 vibrations? If the C^1 makes 529 vibrations per second, the A^1 must make 889.67. As to me, it is all alike, whatever tone you design by the number of vibrations, as I find all the rest, and also all the corresponding lengths of the columns of air, in my diagram directly. I send you now these measures on the enclosed slip of paper. They are all taken from the point where the column of air is shut off by the cork in the head-joint. You will find the length for the A^1 = 332.28 m.m., and for the C^1 = 598 m.m. The number 593.92 indicates the length, in case the foot is made to go down to B♮. In that case the centre of the C^1 hole would be bored at the indicated point. Now a flute made to these measurements would be in the pitch you require with most flute players; but it would not suit *me*, as I always played much sharper than others, on account of my free and open embouchure. There was in my time only old Tulou at Paris, who played at as high a pitch as myself on any given flute; therefore my own flutes must always be longer from the cork to the A^1 by about 3 m.m., and all the rest in proportion. Now, as you write to me that you, too, play with an open embouchure, to get a fuller tone you also will require a longer measurement; and the question is, how much?

This must be ascertained precisely, or you will get a flute not perfectly to your wishes.

You say in your letter, "I have put the head-joint No. 2 into the lower part of the normal diapason flute," and afterwards, "Well, this brings the flute to the pitch I require, or nearly so;" and then you say, "But I find the C^1 too sharp, just as when on any other flute I draw out the head-joint a good deal, I find the

lower C too sharp." My dear Sir, you say here what is contradictory, and quite impossible; as you ascribe the same effect to drawing out and drawing in! A flute can only be *perfectly* in tune in the diapason corresponding to its measurements. If you draw *out* or *in* more than a couple of millimetres |ı| , the intonation must become defective, because all the holes should be regulated in *geometrical* progression ( = 10 m.m.). Now look at the drawing. If you pull out the head 5 m.m. = the effect on the C^2 is twice as great as on the C^1, which requires 10 m.m., instead of 5. The natural consequence is that the C^1 is too sharp in proportion to C^2, and your remark on drawing out is perfectly correct; but if you draw in, or shorten the upper part of the column of air, above where the holes begin, by putting on a *shorter* head-joint, the effect must be contrary, and the C^1 gets too flat in the same proportion. Therefore it cannot be the fact that the C^1 gets too sharp in proportion to the C^2, when a shorter head is used. All such details must be accurately examined. Therefore you must proceed as follows: take your flute with the head which you prefer, and draw in or out till you get the A^1 at the required pitch. When you are quite sure that it is right—taking into account all such influences, as for instance, the temperature of the room, &c., &c.—then lay your flute down, and place my drawing over it, so that the rim of the embouchure in the drawing corresponds exactly with the rim of the embouchure of your flute; then, by stretching out the drawing, you will at once see whether there is any, and if so, what difference in length from the rim of the embouchure to the *centre* of the *A^1 hole.*

Mark this difference on the drawing, and if you do the same for the *end* of the flute also, so much the better. It will show whether you have measured correctly. You will notice that I have marked on the drawing the two measurements which you sent me on slips of paper. Now as you wish me to use the head-joint No. 2 with the new middle and foot-joints, I want to know (for I cannot remember) whether there is on this head-joint a ring; and if so, at what distance from the end? Of late years I have always

made that ring in two separate pieces—one of them soldered to the "box" (Büchse) on the middle joint, the other to the head; so that when the flute is put together, both parts form the complete ring.

As the head ought to go into the "box" (upper part of middle joint) till the end of it reaches the tube of the middle joint, I want to know the length of that part which extends from the ring on the head-piece to its extremity. Mark this also on the drawing, and return it in your next letter. In this way I hope I shall be able to meet your wishes; but I must have measurements on which I can rely. A thread which will stretch will not do.

All the rest I know, and your middle and foot-joint shall be made as well as possible. I wish I could carry out orders more quickly; but since my former pupil, Heindl, travelled through the United States, I have had more orders than I can execute from America; and though I offered to procure flutes from my friend Lot, at Paris, people prefer to wait for those made by myself.

Begging your excuses for my bad writing—I do what I can—I remain, &c.

NOTE.—The above may interest flute players as showing how minutely careful and painstaking Böhm was, and how thoroughly he understood his business.—W. S. B.

(*From the German.*)

MÜNCHEN, *August*, 1871.

To W. S. BROADWOOD.

I am glad that you like the flute. Your notions about tone quite agree with mine. A silver flute is from the first as good as it ever will be, whereas a wooden flute, if properly treated, goes on improving continually. For that, it is most essential to wipe the tube quite dry, and to clean it each time it has been played upon. This, however, can only be properly done when the cork is taken out, and a silk or linen handkerchief drawn through. I have an old cocoa-nut flute which has an excellent tone; but my ideal of tone, large, sonorous, and powerful, admitting of every

gradation from *pianissimo* up to *fortissimo*, is still the tone of my silver flute in G. The effect I have repeatedly produced, when playing it . . . although I am now an old man of 78½, and use false teeth, is such that I only regret that I did not make this flute forty years ago. With a silver head-joint and a gold embouchure, the tone is very brilliant, and no room is too large for it; while with a wooden embouchure on the silver head-joint, the tone gains in richness without losing power.

Compared to the C flute, it is like the voice of a fine powerful soprano in contrast to that of a child. Once when I played in a church on this flute, accompanying a soprano, it was mistaken for a French horn. My work, "Die Flöte und das Flötenspiel," is in the press. I receive proofs for correction every week.

De Vroÿe is a first-rate artist, but his tone is too small for London, where Nicholson is still remembered. I did as well as any Continental flautist in London in 1831, but I could not match Nicholson in power of tone, wherefore I set to work to remodel my flute. Had I not heard him, probably the Böhm flute would never have been made. For of all other flautists, not even excepting Tulou in Paris, no one could do more than I could, so far as tone is concerned. All Nicholson's immediate successors had, more or less, a powerful tone, but they made a trumpet of the flute. Their tone was loud enough, but *loudness* alone is not what is wanted for *singing*. I always prefer quality to quantity.

MUNICH, *Nov.* 8, 1873.

To MR. W. P. MILLS.

I have made myself an exact drawing of the position of the holes, according to the paper slip you had sent me back as being correct; so there can be no mistake as regards the pitch. Next week your flute will be commenced, and if there comes no unexpected hindering, it will be finished in December. I ordered the octave key, which makes much less complication than the shake lever, and which will never come out of order, as the little hole, about as large as ◯, is shut so very easily. I find that little

key very useful, if the player wants to be always perfect in tune in the following notes These tones have always a tendency to get a little flat if played in *pianissimo ;* and if you open the little octave key, they are not only perfectly correct, but sound also very easily. The key can easily be opened with a very small motion of the thumb, and you will get used to it by and by without the least trouble. When not wanted, as, for instance, in rapid passages, it will not hinder your execution. Thus, if you wish to execute

you will hardly play it perfectly without that little key. Now in regard to a second middle joint, I advise you not to have one, as the difference in pitch is much greater in comparison with the normal pitch than it was in your first flute. You will never be able to play in tune if the foot is not conformed, in the position of the holes, with the middle joint. The difference is too great. Not only the lower notes, C^1, $C^1\sharp$, D^1, $D^1\sharp$, will be much too sharp, but also several tones in the third octave will not be in tune, nor sound easily.

It is just as if you had three strings on a violin tuned half a note higher, and leave the lower one half a note too flat! You cannot do without having also another foot, and as the price of a head is very little in comparison with the two other joints, you will do much better to get a second flute at the normal pitch. A middle joint without foot to it is throwing away money!

MUNICH, 1878.

To MR. W. P. MILLS.

As to the preference of wood or silver, that question will never be solved; it is a matter of taste. If you could read what I have said about it in my book, you would find that I myself played best for many years on silver flutes; but took to wooden flutes after I had lost some front teeth, and with them my good embouchure. Silver flutes sound more readily, and are better adapted for modulating tone; but those who have not the right sense and feeling generally produce a hard tone, and therefore do better to play on wooden flutes. I could produce effects on my silver flute which I could never afterwards produce on wooden flutes.

I think Mr. Broadwood, who always endeavoured to get the best tone, will tell you the same.

My eyes get now so weak that I must end.

MUNICH, *July*, 1878.

To W. P. MILLS.

The head-joints of our wooden flutes must be oiled, but *never the middle* or the *foot-joint*. You can apply a little oil (the best is *oil of Provence*) with a feather, when the head is perfectly dry, and when you have taken out the cork. The best time is to oil it in the evening, that the wood may have time to absorb the oil before the morning. Then you wipe it dry with some linen before playing. If you oil the head once a fortnight at first it is quite enough, and afterwards only every month.

I am quite well in my old age of eighty-five years, only my eyes are very bad.

BÖHM'S DIAGRAM.

The German text of Böhm's description and explanation of his Diagram was first published in a special number of the "Kunst- und Gewerbeblatt," Munich, October, 1868. Böhm had previously sent it with a model of his G flute to the Paris Exhibition, 1867, where, however, it was "*mis hors de concours*" by the musical jury, who said they were not competent to decide upon the merits of a production which was scientific rather than artistic. He then, as I have said, published it at Munich, and sent me the copy (of which I have made, I fear, but an indifferent translation), by way of reply to certain questions I had asked.

He subsequently published it in a somewhat, but not materially, different form in his "Die Flöte und das Flötenspiel." I believe the date of this latter pamphlet was 1873, and the publisher, Joseph Aibl, of Munich. In it also he has re-written in German, nearly word for word, several passages of the earlier English pamphlet, now for the first time printed.

Böhm was very anxious that the German (1873) pamphlet should be translated and published, with the earlier one, in England. "Then," he wrote to me, "all that I have done in 60 years will be known." He repeatedly urged me to undertake the task, and this must be my excuse for the present imperfect attempt.

W. S. B.

May, 1882.

On the Method to be adopted in determining the position of the Note-holes of Wind Instruments for every given Pitch. By Theobald Böhm. (*Bavarian "Kunst-und Gewerbeblatt," October*, 1868.)

The manufacture of wind instruments having note-holes, and their adaptation to the various musical pitches, necessitates, for the most part, new calculations or models, which cost time, trouble, and money.

To avoid such inconveniences, I drew out a diagram, on which the basis of calculation is represented and marked out in linear measurement. Thus, in the following table, the reciprocal numerical proportions of vibration to length of string, in the equally tempered scale, are represented by horizontal or by vertical lines; while diagonal lines indicate the geometrical progression in which the longitudinal measurements may be varied without disturbing the proportion which they bear to the vibrations.

TABLE.

	Number of Vibrations.	Lengths of String.
C^1	1,000.000	1.000,000
C♯ ... D♭	1,059.463	0.934,874
D	1,122.462	0.890,899
D♯ ... E♭	1,189.267	0.840,896
E	1,259.921	0.793,701
F	1,334.840	0.749,154
F♯ ... G♭	1,414.213	0.707,107
G	1,498.306	0.667,420
G♯ ... A♭	1,587.400	0.629,961
A	1,681.793	0.594,601
A♯ ... B♭	1,781.796	0.561,230
B	1,887.745	0.529,730
C^2	2,000.000	0.500,000

NOTE.—I have used the term *longitudinal measurement*, throughout this translation, to express *measurement in length*.—W. S. B.

The representation on a diagram of the reciprocal proportions of musical notes in their geometrical progression was suggested by the drawing of a monochord, having a stop, movable along the stretched string, which it gradually shortened, so as to give at the several points of stoppage the several intervals into which the octave is divided.

Now these proportions hold good throughout the whole range of musical notes. They apply, therefore, to the transition from any one note to that next in order to it; and the transition itself can be figured.

I have founded my diagram on these considerations. With its help, and without resorting to calculation, the centres of the note-holes on all wind instruments constructed on my system may be determined; as also the position of the so-called "frets" of guitars, mandolines, zithers, &c., &c.

To do this, of course, the assumed *relative* or proportional numbers must be converted into *absolute* numbers of vibrations and *positive* longitudinal measurements.

As the French normal pitch ($A^1 = 870$ vibrations) is now adopted nearly everywhere, I have founded upon it the numerical calculations of my Diagram; and as unit of calculation for the longitudinal measurements, I have taken a cylinder open at both ends, 670 m.m. in length, and giving the note $C^1 = 517.30$ vibrations of the French normal pitch.

Thus we obtain the following proportionate numbers :—

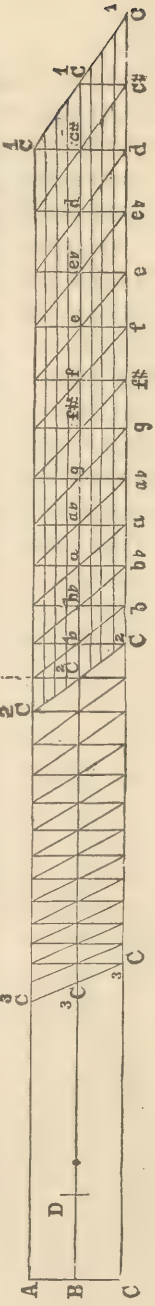
Absolute number of Vibrations.		Relative Longitudinal Measurements. Millimetres.
C^1	517.30	670.00
C♯ ... D♭	548.06	632.39
D	580.65	596.90
D♯ ... E♭	615.18	563.40
E	651.76	531.77
F	690.51	501.93
F♯ ... G♭	731.57	473.76
G	775.08	447.17
G♯ ... A♭	821.11	423.07
A	870.00	398.38
A♯ ... B♭	921.73	376.02
B	976.54	354.91
C^2	1034 60	335.00

The relative longitudinal proportions of my flute, here expressed in millimetres, are, of course, merely adopted for the purpose of illustration. Although the vibration numbers of the normal pitch, asal so the longitudinal proportions for all instruments are constant, yet each wind instrument has its special length, which depends upon

the means by which tone is generated. The tube of an oboe, and more particularly that of a clarinet, must be made very much shorter than the tube of a flute of like pitch, because of the flattening influence of the reed or mouth-piece. For only a small portion of the air-column, corresponding to that note which the mouth-piece or reed when blown separately would give, is really, there. Wherefore a wind instrument, when shortened by one-half its length, will not give the octave of its fundamental, but a considerably flatter note.

The length for the octave must therefore be ascertained by calculation, or simply by shortening the tube. Then, by doubling the length of the shortened tube, an air-column is obtained, answering to the string of a monochord, and which may be divided into intervals, so as to coincide with the numerical and longitudinal proportions given in the diagram.

Now the flattening influence of the cork and the embouchure amounts on my flute to 51.5 m.m., and in calculating the relative longitudinal measurement of intervals this has to be taken as an actually existing length; therefore, in the practical application of the formula this quantity (51.5 m.m.) has to be deducted from each relative longitudinal measurement. For instance, $C^1 = 670.0 - 51.5 = 618.5$. The perpendicular line at B shows the place where the air-column is terminated by the cork; and a shorter line at D indicates the centre of the mouth-hole. All positive or actual measurements taken from B should be shorter by 51.5 m.m. than the corresponding relative longitudinal measurements given on the diagram.



EXPLANATION OF THE DIAGRAM ON PRECEDING PAGE.

My diagram consists of three horizontal parallel lines A, B, and C, representing longitudinal measurements, the divisions of which are shown equally on all three lines by vertical sections.

The central line B represents an air-column—answering to the string of a monochord—contained in a cylindrical flute tube, open at both ends, and whose fundamental note is the C^1 of the French pitch ($A.^1 = 870$ vibrations). The entire length of this air-column, and therefore of the line B, gives the fundamental $C^1 = 670$ m.m. And the sectional lengths for the chromatic scale, expressed in millimetres, and calculated from the actual vibration numbers of that pitch, are shown by the intersections of the line B with the vertical lines. Thus a standard measure, expressed in millimetres, and taken from the upper extremity of the diagram, is established on the line B; and it will show the actual dimensions of my flute measured from the cork, when the 51.5 m.m. before mentioned shall have been deducted from each of the relative measurements.

The positions of the centres of the tone-holes on this standard only tally with the normal pitch ($A_1 = 870$ vibrations). That they may correspond with other pitches, provision must be made for varying the reciprocal distances without disturbing their reciprocal proportions. This can be done, without resorting to calculation, by means of the diagonal lines marked on the diagram.

These diagonal lines extend upwards and downwards, from the points of intersection with line B, to the points on the parallel lines A and C, where the reciprocal distances of the tone-hole centres are shown, sharpened (shortened) above, or flattened (lengthened) below by a half-tone.

The pitch of a flute made to the shortened measurements of line A will, therefore, be exactly half-a-tone sharper, and that of one made to the lengthened measurements of line C half-a-tone flatter than the normal pitch.

Now, as these diagonal lines may be looked upon as a prolonged series of tone-hole centres, which gradually approach each other above, or recede from each other below, in the same geometric proportion; it follows that the reciprocal longitudinal proportions of these

tone-hole centres remain unchanged throughout, be the point of intersection of the diagonal with the additional parallel line where it may.

It follows that every additional line drawn parallel to, and at any given distance from, line B establishes a new series of measurements, in which the distances of the tone-hole centres, while retaining the same geometrical progression, will correspond to a pitch whose difference from the normal diapason will be proportionate to the distance from line B (whether above or below it) at which the new parallel line is drawn.

And as it is shown on the diagram that the tone-hole centres move horizontally also, in the same geometrical progression, towards or from the cork, along the parallel lines introduced for the purpose of illustration, therefore the difference of pitch for any one note will be proportionate to the distance of that particular point of intersection from the upper end of the air-column, or from the vertical line of section of the corresponding note.

To determine the point on the diagram where a new parallel line should be drawn, so that the tone-hole centres to be marked on it shall correspond to the pitch of a given note, the difference in pitch of this note from the normal diapason must be expressed by longitudinal measurement in millimetres. Thus it will be seen by how much the length of the air-column (given in metrical measurement on line B) must be diminished or increased to make it agree with the pitch of the given note; and the same process defines the position of the vertical line of section corresponding to the given note.

If, however, the difference of pitch is expressed in number of vibrations, its conversion into metrical measurement is effected as follows. The number of vibrations being inversely as the length of air-column, the following two geometrical proportions arise:

	Vbr.		Vbr.		Relative Length	
(a*)	860	:	870	=	$398.38^{m.m.}$	: L1

$$L = \frac{870 \times 398.38^{m.m}}{\text{Vbr. } 860} = 403.01^{m.m.}$$

(b*)	890	:	870	=	$398.38^{m.m}$	: L2

$$L = \frac{870 \times 398.38^{m.m.}}{\text{Vbr. } 890} = 389.42^{m.m}$$

The vibration numbers 860 and 890 are to the normal vibration number 870, as the normal-pitch-relative-length 398.38 m.m. is to the required length.

If 870 be multiplied by 398.38 m.m., and the result (346,590.6) divided by 860 or by 890, the figures thus obtained (viz., 403.01 and 389.42) will represent in millimetres the relative longitudinal measurements into which the number of vibrations will have been converted. As these relative longitudinal measurements correspond to the given vibration numbers 860 and 890, the longitudinal differences (4.63 m.m. and 8.96 m.m.) from the relative longitudinal measurement of the normal diapason must correspond to the difference in number of vibrations—viz., to 10 and 20, respectively.

The required point of intersection will be indicated by that of the horizontal line, with the diagonal leading upwards, when the measurements are shortened ; and conversely, by its intersection with the diagonal leading downwards, when the measurements are lengthened.

The conversion of the difference of pitch into measurement expressed in millimetres may be effected either by actual measurement, or by a simple calculation, according as the pitch to which the instrument is to be made is indicated by a tuning-fork, or by a given number of vibrations. For instance, if $A^1 = 860$ vibrations (that is, 10 vibrations flatter than the normal diapason) is given by a tuning-fork, then the head-joint of a flute at the normal pitch must be drawn out till its A^1 is exactly in tune with the given A^1. Then, assuming the tuning to be absolutely correct (this of course the ear must decide), the length drawn out will be found to be 4.63 millimetres.

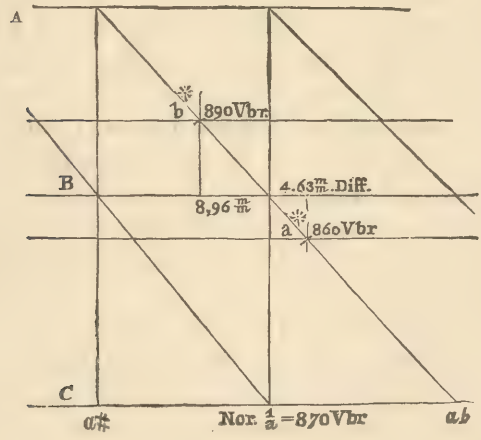
If the given pitch is sharper than the normal diapason, say for instance, $A^1 = 890$ vibrations ; then the head-joint of the normal pitch flute must be drawn out still farther, till its $A^1\sharp$ or $B^1\flat$ is in tune with the given A^1. In this case the length drawn out will be 13.40 millimetres, and the column of air giving $A^1\sharp$ or $B^1\flat$ at the normal pitch will have been lengthened by thus much. Therefore, the vertical line of section, to correspond with the given $A^1 = 890$ vibrations, must be drawn upon line B at a point distant 13.40 m.m.

from the centre of tone-hole $A^1\sharp = B^1\flat$, on the side towards tone-hole A^1.

Therefore, a line of section drawn at right angles to line B, and distant 4.63 m.m. from the centre of the tone-hole A^1 on the side towards $A\flat$, will correspond to the $A^1 = 860$ vibrations; while a second such line, drawn at a distance of 8.96 m.m. from the same tone-hole centre, but on the side towards $A\sharp$, will correspond to the $A^1 = 890$ vibrations.

The diagonals leading upward and downward will (as already mentioned) show the required points of intersection.

The results thus obtained will be found to be perfectly accurate.



As the relative proportions of vibration numbers to longitudinal measurement upon the diagram remains the same throughout, it is immaterial whether the note given be an A, a C, or any other; and if the diagram should not be long enough to show the position of the lower notes, it can easily be lengthened. All the longitudinal measurements must be doubled for each successive lower octave.

Inaccuracies of drawing could hardly escape notice; they would at once be shown by the diagonal lines.

APPENDIX.

THEOBALD BÖHM.

(To the Editor of the "Musical World.")

Sir,—I notice in your contemporary, the *London Figaro*, charges brought against the late Theobald Böhm, of Munich, which are, as I think, both inaccurate and misleading.

The *Figaro's* correspondent seems to consider that the main feature in Böhm's improvement of flutes was a system of fingering generally, erroneously, he says, attributed to him, but in reality "annexed" from one Captain Gordon. This it was, says the *Figaro's* correspondent, which made Böhm's name famous. Gordon, we are told, invented and perfected this fingering; and after vainly advertising it throughout Great Britain, France, and Germany, he died of a broken heart, maddened by his failure to sell his invention, and by Böhm's "annexation" of it. We are not told why, what in the one case failed so signally, succeeded in the other so completely.

In justice to Theobald Böhm, whom I knew very well for nearly forty years, I venture to suggest an explanation:—He was a man of very considerable scientific, as well as technical attainments. Originally a gold worker, he subsequently became an inspector of mines; besides being for many years first flute in the principal orchestra of Munich. Whether he did or did not borrow ("annex" if the *Figaro's* correspondent prefers that term) the first notion of what Sir H. Bishop in his 1851 Exhibition report calls a system "for reaching and stopping the flute holes at great distances," is not very material. Böhm always claimed the invention of fingering known by his name; and I am not aware that it has ever been proved that Gordon's fingering was identical with it. The question which the *Figaro's* correspondent begs, and on which he founds very serious charges has, as he admits, been debated very "fiercely," but

not conclusively settled. Be that as it may, Böhm soon perceived that the really essential points to be determined with a view to the improvement of his instrument, were: (1) The shape and proportion of the tube, more particularly of that part known as "the head," where sound is generated; (2) the exact position and proportion of the "embouchure" and finger-holes. In order to solve these problems, Böhm set himself to study acoustics, under the well-known Professor Schafhäutl; and after several years' labour produced as a result: (1) "a cylindrical tube with conical head;" (2) "a geometrical diagram (I now quote from Mr. Pole's report, 1862), with explanations, by which makers of tubular instruments can with the greatest accuracy construct their instruments according to any of the recognized pitches."

It is upon these calculations, and upon their practical application, that Böhm's fame rests. It is no exaggeration to say that their publication produced a revolution in the manufacture of wind instruments. So little did the merit of Böhm's invention depend on any one system of fingering, that it was applicable not to flutes only, but also to oboes, clarinets, and bassoons, which are fingered quite differently. At the Exhibition (1851) competent and impartial musical judges pronounced it to be "an *entirely new* and scientific system of construction, which has done more than anything else to lift this class of instruments to their present degree of perfection, both of intonation and of *timbre*."

If Böhm, originally, like Captain Gordon, a poor man, had, like him, relied solely on a novel system of fingering, he would probably have been as unsuccessful. In our day, nearly every flautist has his own pet system of fingering, of which he proclaims the superiority, and which, at all events, suits *him* best. Several of these have been adapted to Böhm's tubes, with more or less success. That Böhm did not "annex" his scientific knowledge may easily be proved. His letters, of which I have still a considerable number, prove it conclusively. The head of the Pulteney Street firm—whose intimate practical knowledge of everything connected with the manufacture of pianofortes will be contested by no maker, whether English, French, or German—has repeatedly and ungrudgingly acknowledged

the assistance afforded him years ago by Böhm when calculating what is termed the scale of grand pianofortes. He told me that he found Böhm very well versed in the acoustical bearings of that subject. But, to quote the *Figaro* correspondent's words, "it is an old tale," that of disputed inventions. A crude idea occurs to one man; it is developed and carried out, perhaps, by another. The former may have had neither the knowledge nor the perseverance necessary to mature his notion into practical utility; yet he eventually claims, or his friends claim for him, all the merit of the invention.

The French point triumphantly to Papin, the inventor of steamboats, as they assert, in Louis XV.'s time. My friend, Mr. Hipkins, in his very able and interesting paper (see "Grove's *Musical Dictionary*"), shows, with more probability, that Cristofori invented pianofortes. For the sake of argument, let us associate with them Gordon, as the alleged inventor of the Böhm fingering: originator, if I rightly understand the *Figaro's* correspondent, of the most material modern flute improvement? What would any of these, in their very different degrees of importance, say to their bantlings now full grown? Would they even recognize them? And what are *we* to say to those—if such, indeed, there be—who would claim for the putative progenitors all the merit?—I am, sir, very obediently yours, WALTER STEWART BROADWOOD.

Cabalva, Radnorshire, Jan., 1882.

(To the Editor of the "Musical World.")

SIR,—The German manuscript of the accompanying paper, with a translation by himself, which I have since re-cast, was sent me by Mr. J. P. Triggs, flautist, of Glasgow. He tells me that he received the manuscript, corrected and signed in Dr. Schafhäutl's handwriting, from Mr. Schmidt, the publisher, of Heilbronn. I do not know whether it has been published in Germany, but I believe that it contains matter likely to interest English flute players, and settles authoritatively the much-debated question as to the invention of the Böhm flute.—I am, sir, very faithfully yours,

Cabalva, Radnorshire, Feb. 13th, 1882. W. S. BROADWOOD.

THEOBALD BÖHM, AND THE FLUTE CALLED AFTER HIM.

It seems that the old dispute as to who was the real inventor of the "Böhm Flute" has again cropped up. It originated in Paris.

The celebrated flautist, V. J. B. Coche, who was one of the first to play the Böhm flute; who contributed more than anyone to bring it into use in France, and who explained its merits in a pamphlet of his own composition (Paris, 1839), writes to Böhm, May 25th, 1838: "On dit dans le monde artiste, que la flute qui porte votre nom a été découverte par un nommé Gordon ancien élève de Drouet."

The Gordon in question was a Swiss, who had served as officer in the Garde Royale of Charles X., and had been pensioned after that King's abdication. He heard Böhm play upon his ring-keyed flute at a concert in London (1831), made Böhm's acquaintance, and conceived the idea of himself making a new flute that should be free from the defects of the old flute. We shall become better acquainted with this "new flute." Gordon worked at it in Paris indefatigably with his own hands, and showed it to his teacher, Drouet. In a letter dated Feb. 15, 1833, he writes to Böhm: "J'ai vu Drouet à Paris; mais il recule devant un changement dans le doigté. Tulou en est là aussi."

That Drouet and Tulou should have remembered Gordon when Böhm came forward with his own flute is easily to be accounted for; but that they should distinguish what was the fundamental principle on which the flutes of Gordon and of Böhm were constructed is more than could be expected of most artists; besides which, they were reluctant to acknowledge that the new was more and more superseding the old flute; for Coche had already won over all musicians by his performances on the new Böhm flute.

I have frequently written concerning its origin; for instance, in *the Official Reports of the London Industrial Exhibition*, 1851 (*Berlin*, 1852, *pages* 882-884); again, in *the Report of the Jurors' Committee, Munich Industrial Exhibition*, 1854 (*Munich*, 1855, *pages* 444-446); and, finally, in greater detail, in the *Allgemeine Musikalische Zeitung, Leipsic*, 1879, *No.* 39, *pages* 643-646.

Now that Gordon and Böhm are both dead, the former long since, the latter only towards the end of last year (November 25), I feel myself doubly impelled to make it clear to the musical public, that Theobald Böhm is indeed the inventor of the flute which bears his name.

The eminent flautist, Theobald Böhm, was gifted not only with musical talent, but possessed also a genius for mechanism. After his appointment to the Royal Bavarian Orchestra in 1816, he made several cleverly designed flutes, with a special arrangement of key-mechanism, for himself and for his master, Kapeller, also a member of the Royal Orchestra; and, finally, in the year 1828, he set up a flute manufactory of his own in Munich. From this period dates the gradual adoption in England and France of the excellent system of key-mechanism, designed and made by Böhm himself. The great success which Böhm achieved as a flautist in Munich and in Switzerland induced him at length to visit Paris and London, where the artistic refinement of his style, the fluency and certainty of his execution, commanded general admiration. In London the extraordinarily large tone of the flute player Nicholson, at that time so celebrated in England, surprised Böhm, who hastened to make his acquaintance, and soon found that the secret of the power of the Nicholson flute lay in the unusual size of the holes. But, even so, the capabilities of the instrument were very limited, for, except that of F, no scale was quite in tune. The scales on the Böhm flute were all in better tune than those upon the Nicholson flute, as at that time manufactured by the English makers. Böhm had long been thinking of making a flute which should combine fulness of tone with accuracy of intonation; but he foresaw that this could not be accomplished without a change of fingering, and he knew how difficult it would be to induce musicians, who had practised one system all their lives, to take to another. During this visit to London, however, he finally resolved to carry out his long-cherished purpose.

In December of the year 1832, his new flute, with its new scale, was finished. He soon mastered the new fingering, and in the succeeding year, 1833, played it in Paris, and also in London, with great success.

Savart, the professor of acoustics, at first received Böhm very coldly, and declared that to play the scale on the flute in tune in all keys was impossible; but when he heard Böhm do this, he was so astonished that he himself introduced Böhm to the Academy.

In London, Böhm created quite as great a sensation as in Paris. He particularly impressed Gordon, a retired officer of the Garde Royale of Charles X. Gordon, who was a pupil of Drouet, and an enthusiastic flute player, at once comprehended the advantages of the Böhm flute, renewed his acquaintance with Böhm, and was initiated into his system. He induced Böhm to have a flute tube made for him at Munich by his best workman, but without keys; for he believed that the Böhm mechanism could be simplified so as to require eight keys only. To this notion he clung to the end of his days, undeterred by constant failure, or by Böhm's warning, that to obtain power, equality, and freedom of tone, together with fluency of execution and accuracy of intonation, with a flute having thirteen sound-holes and only eight keys, was an impossibility. This notion of Gordon's had already become a sort of monomania. He clung to it to the end of his life—a very sad end, as we are told.

Gordon left London "peu de temps après votre départ pour Munich," as he writes in a letter of the 15th February, 1833. He was then working, as we have seen, at a flute with the thirteen holes of the Böhm system, but with only eight keys, which, as he wrote, he himself had made. This flute was barely playable in slow movements. In rapid passages the very unequal tone frequently missed altogether. Gordon, however, ascribed these ever-recurring difficulties of execution to bad workmanship; so that he looked upon the flutes he had made thus far as mere models.

In a letter from Lausanne, dated February, 1833, which lies before me at this moment, he requests Böhm to have a flute made by one of his very best workmen on his (Gordon's) model. Böhm answered that it would be better that Gordon should come to Munich. He followed this advice, and arrived in Munich, July, 1833, where he remained till March, 1834; Böhm placing at his disposition one of his most skilful workmen, but being himself away in London.

Model after model was made and rejected one after another. I myself at first witnessed these unsuccessful attempts. At length a well-made flute upon Gordon's model was finished, and he at once brought his invention before the public. In 1834 Gordon advertised his new flute in Paris, under the name of *La Flûte Diatonique*, and brought out a lithographed "Table of Fingering" for it.

In the introduction appended to his Table of Fingering for the Flûte Diatonique, "fabriquée dans les ateliers de Böhm," he says:—

"La suppression des deux clefs de Fa dièze est une idée dont l'application offre de grands avantages. *L'idée de cette clef, de Fa dièze, communiquée par M. Böhm de Munich, a été avec son agrément adoptée pour la présente Flûte*, dont elle complète les moyens d'exécution." This diatonic flute had, of course, the thirteen holes of the Böhm system; five of which remained open for the fingers (E, F, F sharp, B, and C sharp).

Gordon's eight keys, intended for the other eight holes, were connected with each other by contrivances of all sorts—a very puzzle of levers. Above the D sharp hole were the ends of three keys, close together. Five keys had ends shaped like hackers (like the crescent of the moon five days before new moon), and these were for the shakes. They were placed in the shape of a sickle round the holes, so that when one key was pressed down it closed two adjoining holes. Gordon worked on with Böhm's best workman (Böhm himself being again away) with great perseverance, but none of his diatonic flutes satisfied him. At length, despairing, he went back to Switzerland, and we have no reliable account of what became of him and his flute. It was reported that he threw it into the Lake of Geneva, and died in a mad-house. His one fixed idea appears to have completely overmastered the intellect of that gallant and amiable gentleman.

In that same year (1833) Böhm went again to London, and created so great a sensation that the celebrated Dorus*, then a young man, at once laid aside the old flute, and with his wonted

* It was, I believe, Dorus who introduced the closed G sharp key, which is in general use among French flautists.—W. S. B.

energy and talent soon mastered the Böhm flute. In 1837 the Böhm flute was introduced into the Paris Conservatoire, after a committee—of which Savant, Prony, and Dulong were members—had borne the highest testimony to its merits.

In 1846 Böhm crowned his invention by substituting a cylinder for the old conical bore; he also introduced that parabolic curve in the head-joint, which is necessary for correctness of intonation in the high notes. This flute obtained the Gold Medal at the Universal Exhibition (London, 1851), Berlioz taking an active part in the decisions of the jurors. Also at the Paris Exhibition, 1855, it carried off the Gold Medal, to which was added a most flattering acknowledgment of the merits of Böhm's system. At the present time the Böhm flute is played upon all over the civilized world.

Those who know how great is the distance which separates the conceptions of even the happiest ideas from their realization and introduction in a practical form will see a proof of the value of Böhm's system in the fact that it has at length established its position in the musical world, notwithstanding the long-continued opposition of many leading artists. In a letter to Böhm, already quoted, Gordon writes that Drouet and Tulou approved of his flute, but would not hear of a change of fingering.

Böhm's flute would have been rejected for the same reason, had not its superiority been such as to throw into the shade all others, old or new. Thus I have again related in its general outlines the history of the invention and development of the Böhm flute. Probably I am the best witness as to the whole matter, for I lived over fifty-two years with my friend Böhm; under my guidance he devoted himself most perseveringly to the study of acoustics. I witnessed his innumerable experiments, which embraced all wind instruments, and which could only be carried out by one who united in his own person a practical knowledge of technical mechanism and acoustic science.

That such a man should have borrowed from others the ideas upon which he founded the construction of his instruments is what no one can seriously believe.

In latter years Böhm extended the compass of the flute, carrying

it down from C to the low G, thus adding a new, powerful, and effective instrument to the resources of musical art.* His key-mechanism, now used upon all keyed wind instruments of the better class, have already secured for Böhm a permanent place in the history of musical instruments. The keys upon the foot-joint of the flute, formerly supported by "cheeks" cut out of the wood, and having a brass pin for axle—also the equally clumsy metal cups—were replaced by small pillars and slender steel rods and axles, revolving in the ball-shaped extremity of the pillar, and working with the accuracy and precision of a chronometer. The delicate steel springs of the mechanism furnished the means of uniting the action of keys placed at opposite extremities of the flute tube, and enabled the performer to cover a distant hole as perfectly, and with the same certainty, as if the key lay beneath the finger. Keys are indispensable for the large holes of the Böhm flute; they cannot be covered by the unaided finger. Upon the old flute the keys opened small holes; upon the Böhm flute the keys hermetically close large holes. Böhm made, with his own hands, the first batch of his flutes, and accustomed both his workmen and his successor† to such finish of mechanism as has seldom been equalled and never surpassed.

(Signed) Dr. Carl von Schafhäutl,
Koeniglich Akademiker, Conservator und Universitäts Professor.

Munich, January 23, 1882.

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* This is an allusion to the G (bass) flute, brought out only a few years ago by Böhm, and used, I am told, in some German orchestras to produce special effects. —W. S. B.

† Mr. Mendler, of Munich.—W. S. B.

Henderson, Rait & Spalding, Printers, 3 & 5, Marylebone Lane, London, W.

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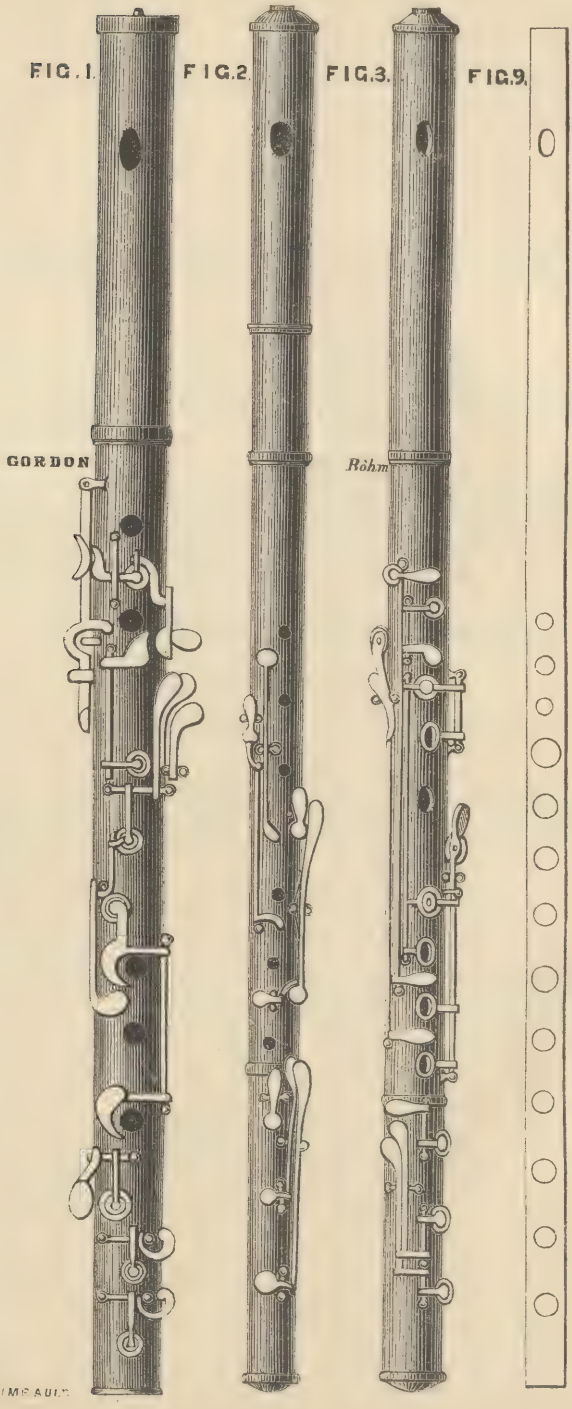


FIG. 1.
FIG. 2.
FIG. 3.
FIG. 9.
GORDON
Röhm

TRANSVERSE
VIBRATIONS.
LONGITUDINAL
VIBRATIONS.

F. IMBAULT

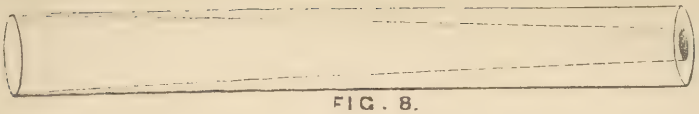
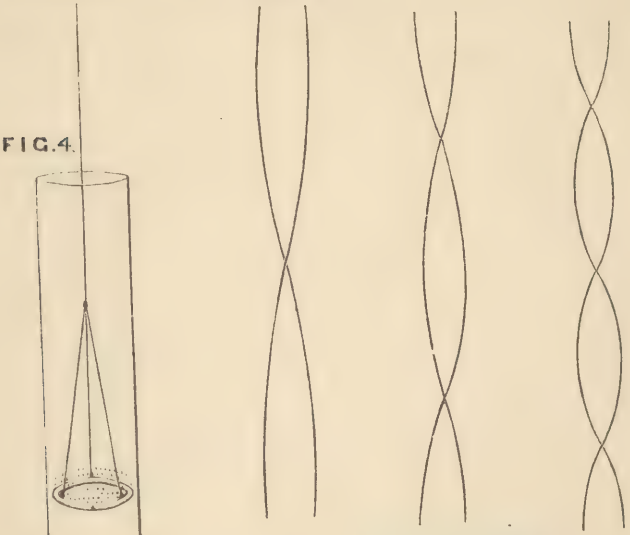


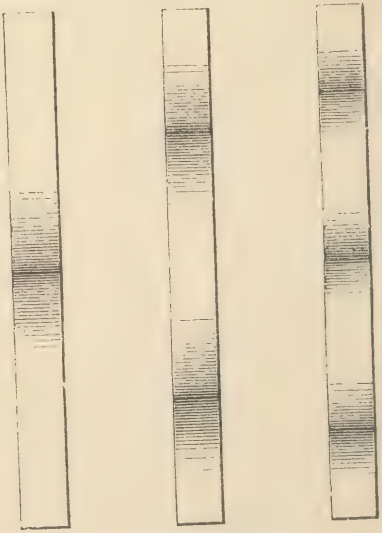
FIG. 8.

FIG.4.



TRANSVERSE VIBRATIONS.

FIG.5. FIG.6. FIG.7.



LONGITUDINAL VIBRATIONS.